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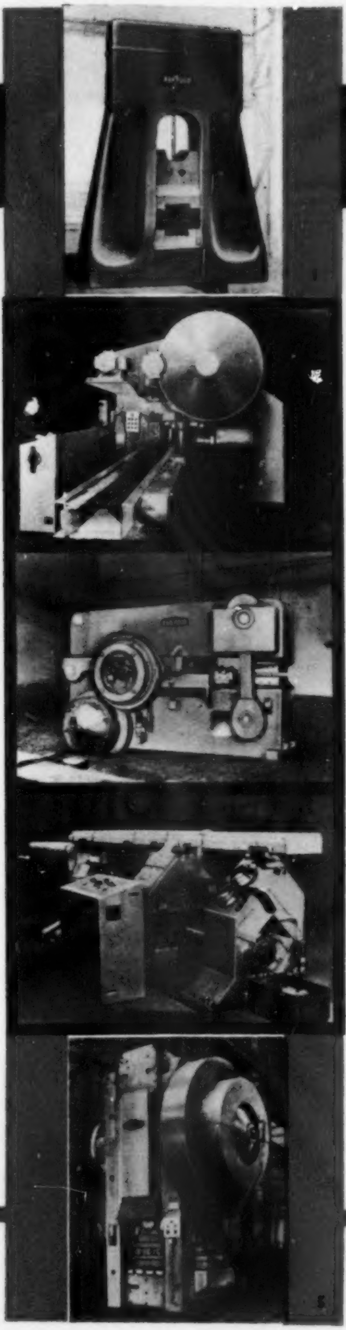

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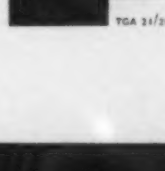

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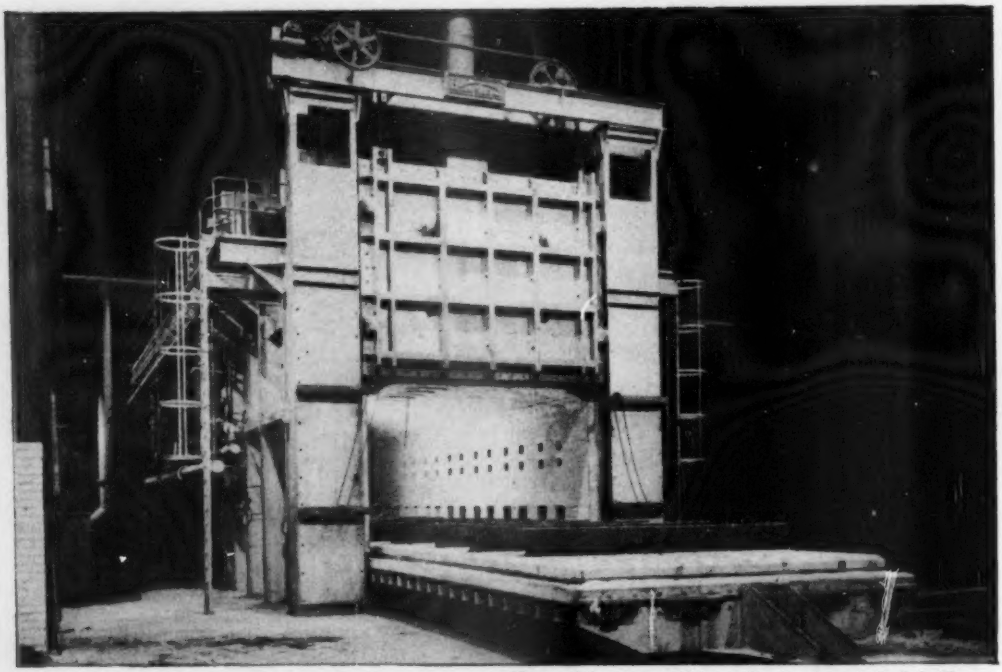

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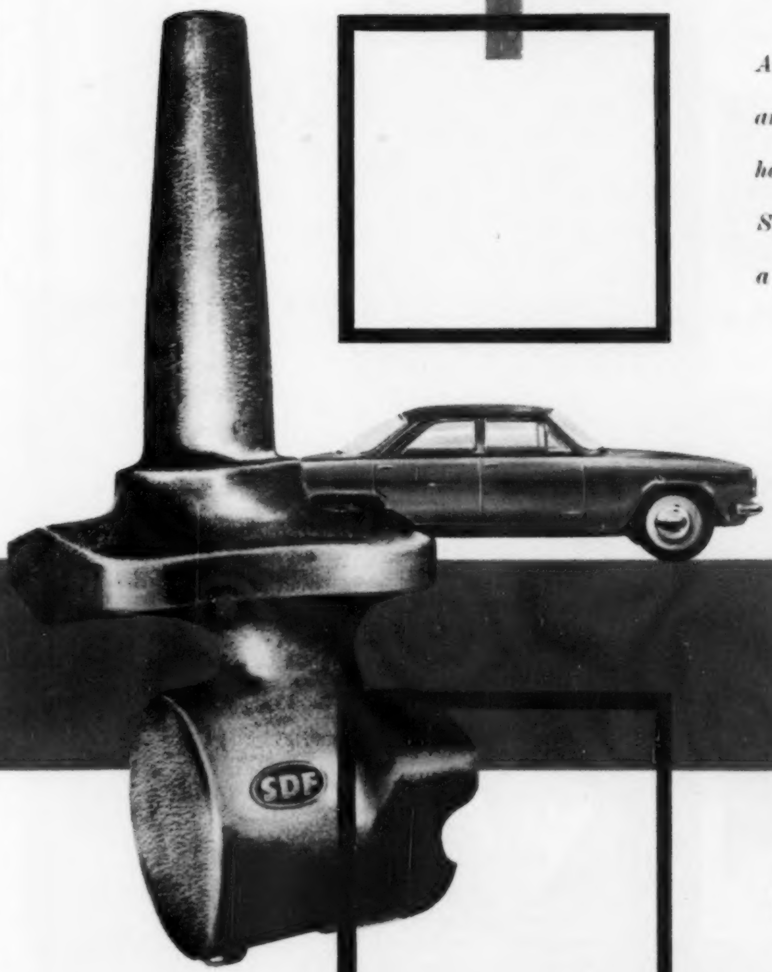

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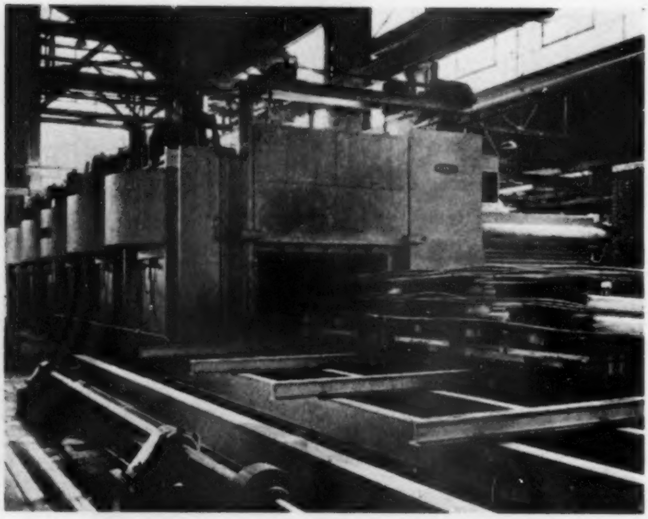

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In the recent large-scale development programme spread over some 30 months, the Northern Aluminium Co. Ltd. has introduced considerable quantities of new plant and handling equipment. A new batch-type furnace, designed and erected by G.W.B. at the Banbury Works of Northern Aluminium, was part of this programme. Production at Banbury, both in aluminium and a variety of aluminium alloys, embraces a wide range of sheets, discs and coils.

Owing to the occurrence of a certain amount of work-hardening (8 in. thick ingots of aluminium are hot rolled to a thickness of approximately 0.3 to 0.5 in.) it is necessary for slabs to be annealed prior to being cold rolled to lighter gauges. The rating of this G.W.B. furnace is 1,000 kW and it comprises six independent and automatically controlled zones of equal length. Rating distribution is as follows: Zone 1 220 kW, Zones 2-5 150 kW each, Zone 6 180 kW. *Owing to the high rating, cycle times as low as 4 hours are regularly obtained.* The maximum temperature of the furnace is 600°C, normal operating temperature being rather lower than this figure.

The heating chamber is lined throughout with heat-resisting alloy, backed by a thick wall of Moler insulating bricks, thus reducing heat losses to a minimum. The furnace casing is constructed from sheet mild steel braced with steel rolled sections and fitted with a mild steel front plate. A cast-framed, refractory faced, fully insulated and counter-balanced door, driven by electric motor, is sealed against the furnace face by pneumatic clamps, thus minimizing heat losses at the furnace entrance. The furnace is supported clear of the ground.

Nickel-chromium strip heating elements, arranged on removable plugs, are situated in the roof chamber, and each zone is fitted with a forced-air circulation system directed cross-flow from the fan, through the heating elements contained in the ducted portion of heating chamber, down into the treatment chamber, and back into the fan for re-circulation. Radiation on to the charge is prevented by a special baffle fitted in the roof chamber to separate the heating elements from the actual working area. Baffles, each independently adjustable and extending the full length of the chamber on each side, direct the air flow to give desired flow characteristics and equalise the temperature throughout the working chamber.

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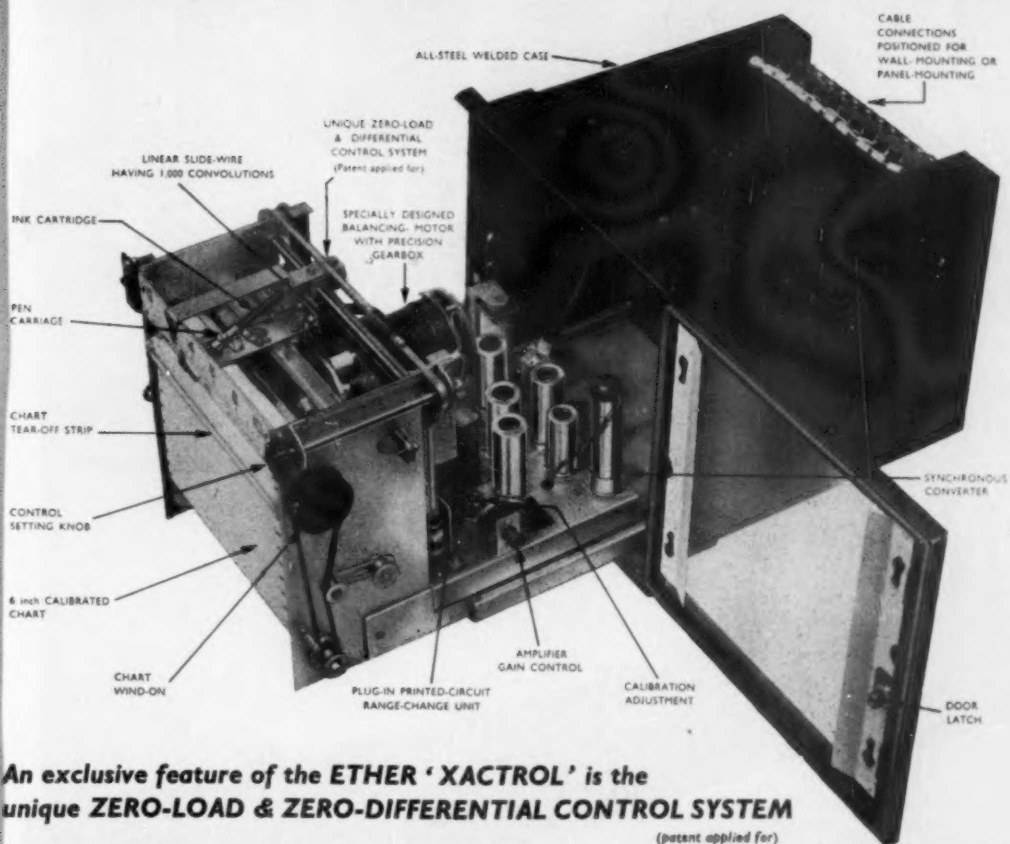

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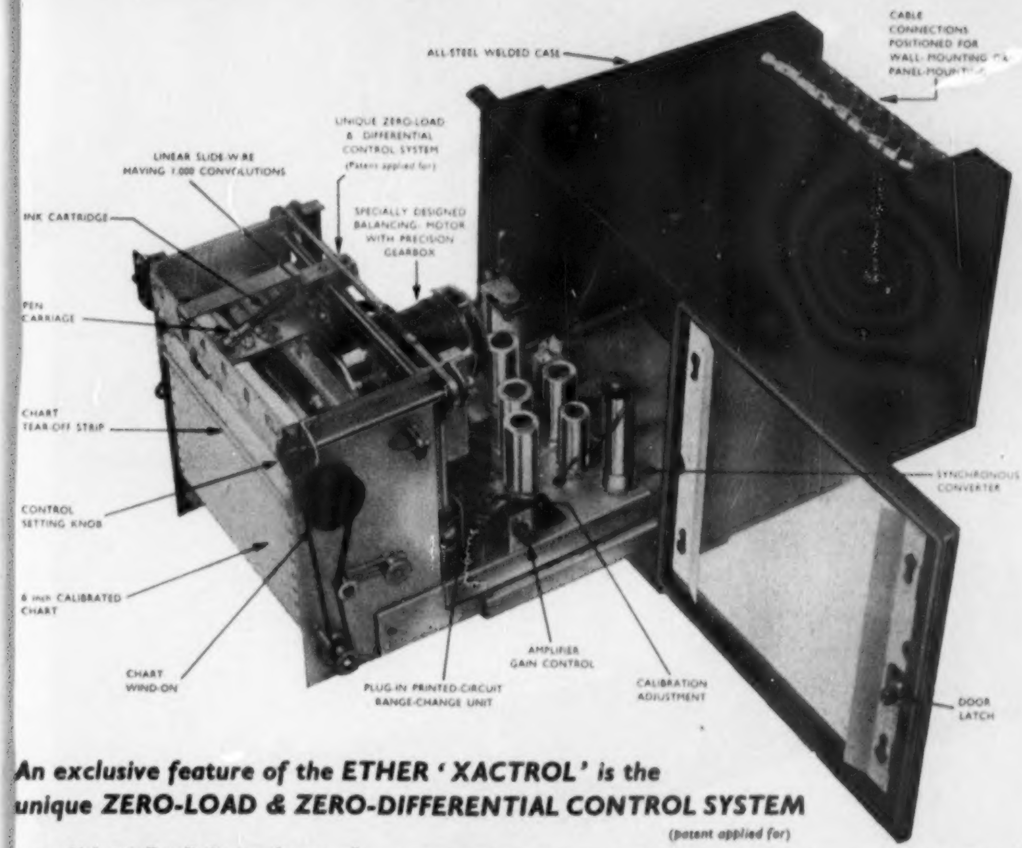

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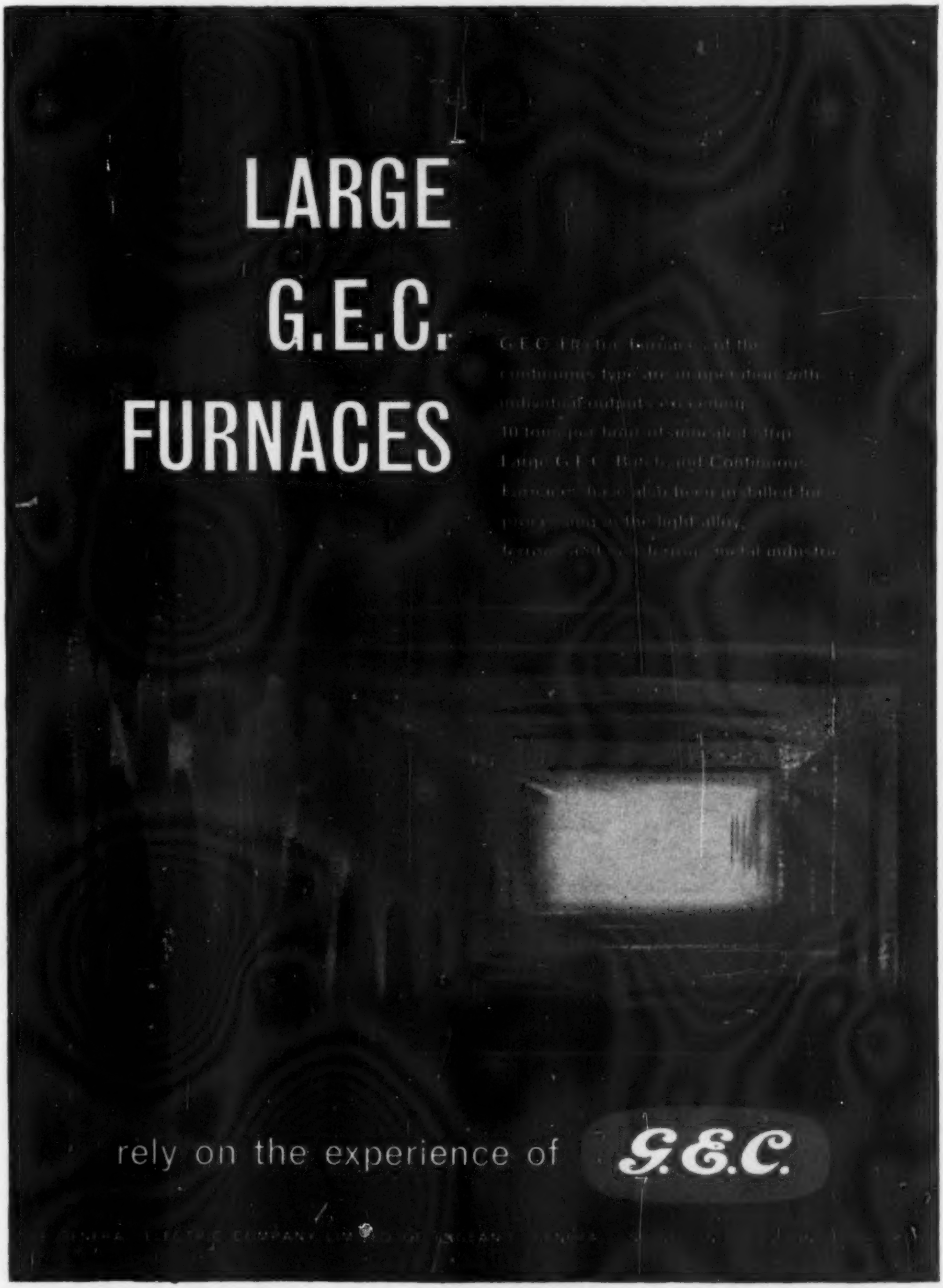
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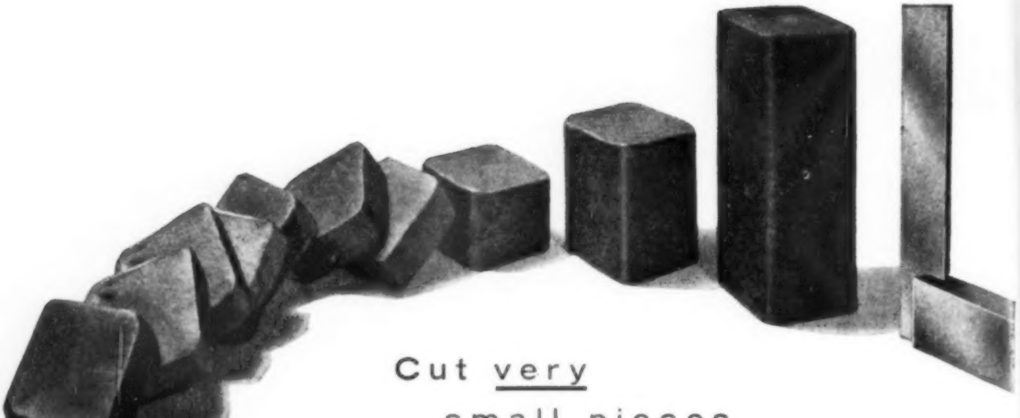

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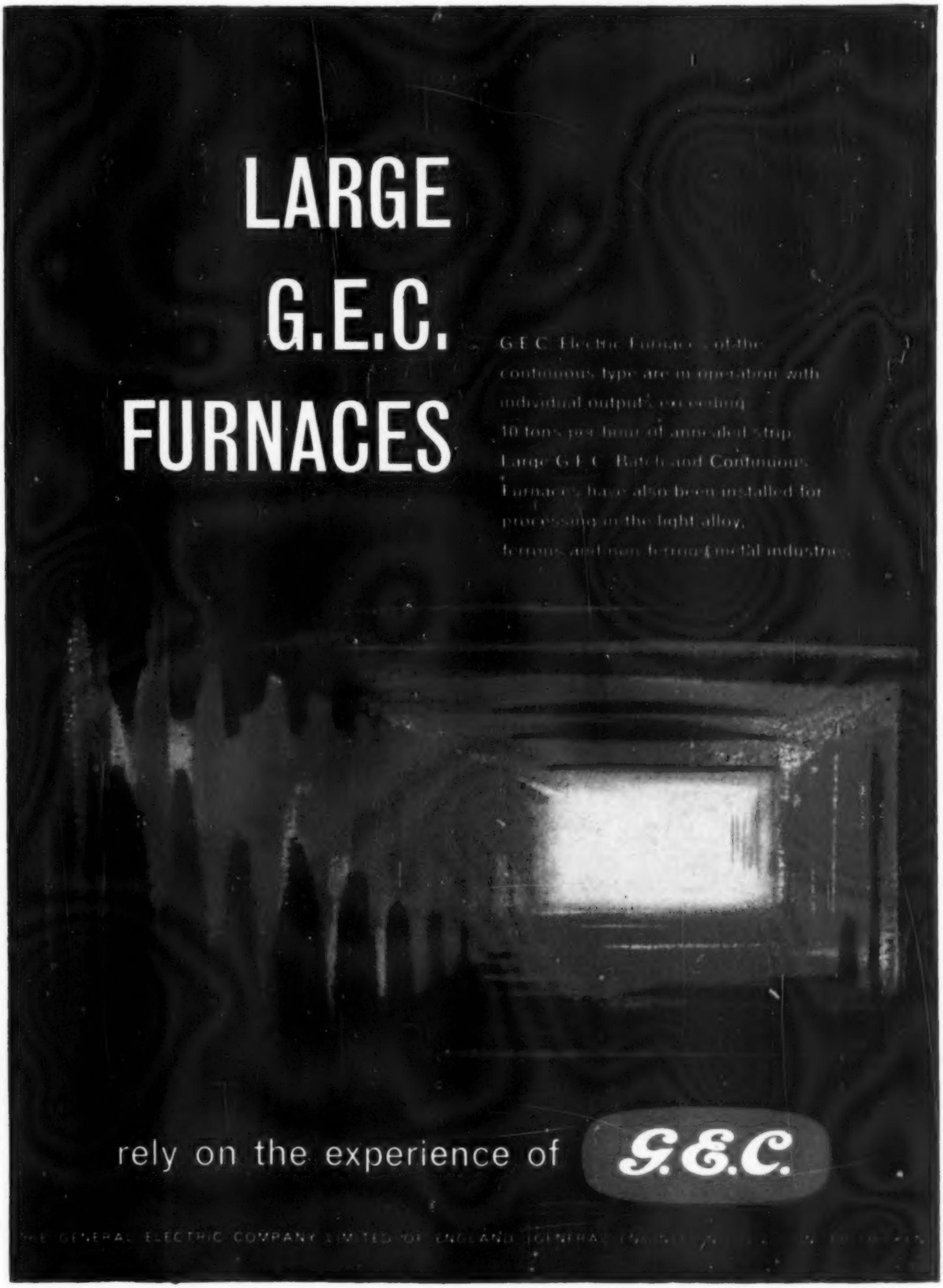
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November 1960

Vol 27, No 182

metal treatment

and Drop Forging

CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

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Trade with Russia

IN spite of the constant tensions of international politics, the Soviet Union is showing an increased willingness in recent years to initiate reciprocal trading with non-Communist countries. One feature of this policy has been the emergence of the Trade Fair as a means of penetrating a barrier which was, at one time, well named the ' iron curtain.' This barrier has, however, been considerably modified in the last few years and many of the remaining obstacles are, one suspects, maintained more by the cumbersome machinery of Soviet bureaucracy than by design.

Last year saw a reciprocal U.S. Exhibition in Moscow and a Soviet exhibition in New York, and now Britain is to hold her own Trade Fair in Moscow next May-June, followed by a Soviet exhibition at Earls Court, London, in July. The British fair is to be held at the Sokolniki Park of Culture and Rest, Moscow, where three foreign exhibitions—U.S., Czech, and Japanese—have already been held. The British fair, however, will occupy almost as much covered area as its three predecessors put together and will be, in fact, by far, the biggest foreign fair yet held in the Soviet Union.

The British fair, which is being organized by Industrial Trade Fairs Ltd., has the specific aim of increasing British exports to the Soviet Union, or rather to sell the exhibitors' products. Exhibitors will be displaying only products which they believe Soviet Foreign Trade Organizations wish to buy, and not products, however interesting, for which there is no Soviet market. This is the main factor which has determined the type of exhibit, and it is this factor which accounts for the high proportion of capital goods being shown.

Both the British and Russian fairs are being held under the joint sponsorship of the Association of British Chambers of Commerce and the All-Union Chamber of Commerce of the U.S.S.R. At a press conference on October 31, Sir James Hutchison, B.T., D.S.O., T.D., J.P., president of the Association of British Chambers of Commerce, said that the value of the reciprocal exhibitions would lie not only in the amount of business transacted on the stands in Moscow and in London but in the contacts established and the information exchanged, which would continue to be a source of great mutual benefit long after the last stand had been dismantled.

Soviet technicians and managers, the representatives of Soviet Foreign Trade Organizations and Regional Economic Councils, would be able to inspect the products of our factories and laboratories, and talk over the specifications and capabilities of the very wide range of materials and manufactures being sent to Moscow, with the men responsible for designing and marketing them. Similarly, our own businessmen would be able to see for themselves at first hand the range of plant, equipment and materials which Soviet factories had to offer them. No one would deny that this was a much more fruitful way of opening up new possibilities for trade, than any amount of discussion in an office two thousand miles or so remote from the actual machine being talked about.

It was also to be hoped that the friendships forged in this way through increased trade with each other would do something to improve our understanding of the Soviet people and their understanding of us. He was, therefore, particularly glad that the Association of British Chambers of Commerce was able to act not only as a sponsor of the British Trade Fair in Moscow, but also of the Soviet Trade and Industrial Exhibition in London. It was a simple and obvious economic fact that trade was a two-way function and both had to continue to strive for an expansion in both directions.

NADFS annual banquet 1960

Personalities seen at the NADFS annual dinner held at Birmingham on November 3 (names read left to right)

(1) *Major-General Sir Francis W. de Guingand,* K.B.E., C.B., D.S.O. *(chairman, Tube Investments, South Africa Ltd.), Brigadier J. A. Barraclough,* C.M.G., D.S.O., O.B.E., M.C. *(chairman, Engineering Employers Association, Midland Area).*
(2) *Mr. Richard Doncaster and the president, Mr. S. Johnson.*
(3) *Mr. R. G. M. Morgan, Mr. H. W. Laskey, Mr. H. M. H. Fox, Mr. R. W. N. Danielsen,* M.B.E., T.D., *and Mr. A. B. E. Lovett (H.M. Superintending Inspector of Factories).*
(4) *The president, Mr. J. H. Swain, past president, and Major-General Sir Francis W. de Guingand,* K.B.E., C.B., D.S.O.

Technical developments in modern drop stamps and forging presses

J. S. BYAM-GROUNDS

This article on the basic factors which qualify the design of drop hammers and forging presses is based on the paper given by the author at the 1960 *Spring Lectures of the National Association of Drop Forgers and Stampers. The first part of the article given last month dealt with the drop hammer and is concluded in this issue with a discussion of forging presses. Mr. Byam-Grounds is deputy managing director of B. & S. Massey Ltd.*

HAVING CONSIDERED the factors governing the drop hammer we turn now to developments in the design of forging presses. Special-purpose forging machinery has been developed for the high production of components in a continuous string by a squeezing and rolling method, but this is limited to relatively few parts which can be really economically produced, that is without excessive wastage of material; the tooling requires special experience and furnacing, for the high throughput is costly. In contrast the forging press still requires to be a versatile machine capable of a very high output on a wide variety of parts.

We have carried out, in my company, some serious experimental work on the cold working of material under the mechanical forging press, largely with a view to studying improvements in the mechanical properties of the product and die design for unsymmetrical components. However, a major field in the development of the forging press is likely to be in mechanical handling by means of transfer tools through the press, automating the process from the furnace to the trimming tools or through a separate trimming machine. The cost of transfer tools is high and some degree of universality must be introduced in the design of the handling gear so that at least it can cope with a number of similarly shaped if differently sized articles, requiring approximately the same number and spacing of impressions on one set of tools. This is a developing field full of interest, again of somewhat special application, and our original work in it was directed towards the production of automotive valves. It is now being developed for a variety of components. It is, of course, only the application of a well-established process in the metal-forming field, but with the difference that in our case we are dealing with material at an elevated temperature which presents a number of special problems.

The design of the automatic forging press does, in certain respects, differ from the conventional form in that if it is to be a continuously running press it requires a very much heavier flywheel and the clutch can be dispensed with. Supplementary drives must be obtained from the main drive to actuate the transfer mechanism and outputs of the order of 100 components per minute can be envisaged. At this rate of output, the material and the design of the die becomes a very important factor as the tools may have to be replaced two or three times a day. They must, therefore, be easily accessible and removable. Water-cooled dies, resistant to thermal shock, may be necessary and dwell time reduced to a minimum.

Until the last few years, the forging press was the prerogative only of the very large forging plant which had outputs or runs of sufficient quantities to warrant the costly dies and bolster sets and the expense of designing them. It was also, in the early days of forging presses, considered that they would be limited to the production of comparatively simple components. As you now well know, there is practically no component that cannot be produced in some way or another under a forging press, so that, while it is still a matter of economics, it is very much easier to keep the press fully employed upon work which it is capable of doing. In consequence of this, the length of run has become less important. The great advantage of the forging press is its reliability and its ability to employ unskilled labour. Speeds of up to 120 strokes min. can be used and, on some special steels, may be necessary. I need not mention the improved form and tolerances of the product obtained by accuracy of guiding and

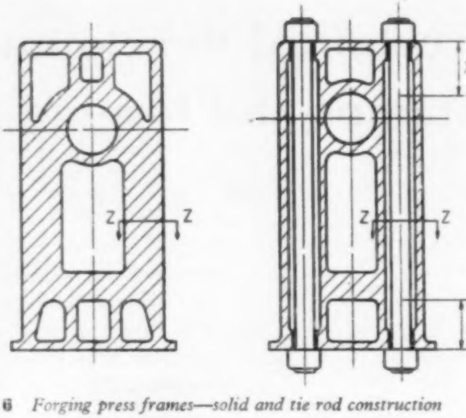
the elimination of draft which is achieved by the extraction under power of the top tool from the workpiece, and the ability to employ ejectors in either top or bottom tools.

The main difference between a forging press and the drop hammer or the screw press is that only as much energy is extracted from the drive, that is from the stored-up energy in the machine, as is required to deform the component. In the drop hammer and in the screw press *all* the energy in the tup or in the flywheel of the screw press must be dissipated in some way or another. In each case the less the energy absorbed by the workpiece, the greater must be that absorbed in the frame elements of the machine with a detrimental effect. It is borne in mind that the tup of the hammer and the screw press are brought to rest at the bottom of the stroke. The forging press only gives up as much energy as is required to deform the workpiece. Now the forging press must fill a particular impression in its one stroke. Therefore, rigidity of the frame is all important. Any excessive elasticity or elongation will lead to the impression not being correctly filled and the possibility, due to incorrect adjustment of the tools, of a jam up. For this reason, the inertia of the moving parts subsequent to the clutch should be reduced to a minimum.

Rigidity in design

This feature of rigidity must apply throughout all components of the press and in the general overall design. I must repeat that it determines in practice the capacity of a press either to do or not to do a certain job. For that reason, the ideal construction is compact, in which the various die impressions are grouped as centrally as possible beneath the main thrust face of the eccentric and in such a way as to distribute the elongation under load as equally as possible on all four columns of the frame. Whether or not the construction should incorporate tiebolts is a debatable subject, ultimately a question of individual preference. From the point of view of mechanical efficiency, a tiebolt construction is undesirable. This is closely analogous to the conditions of a cold-rolling mill where for the same reasons solid housings are essential. With a tiebolt design, metal that could be more usefully employed in a close-ringed mass from the wedge base to above the eccentric bearing has to be distributed over a greater distance so that the actual elongation of the frame is increased by some 50% (fig. 6). This is just what one tries to avoid.

On the other hand, it is argued that the use of pre-stressed tiebolts acts as a safety factor in the event of possible frame breakage due to a faulty casting. This is not necessarily true, as tiebolts can give no protection against weakness or fault in the crown or bottom bridge. For reasons I shall



6 *Forging press frames—solid and tie rod construction*

explain in a moment, a jamming load can cause stresses up to 20 tons sq. in. in a tiebolt frame construction. As from experience we have found the advantage to lie so much in favour of the solid frame we have confined ourselves to adopting the tiebolts only on presses over 2,500 tons in capacity. We have carried out with the aid of the Manchester College of Technology photo-elastic analysis of stress concentration using polarized light in order to design frames against undue concentrations of stress. Modern fault-detecting techniques at the foundry are accepted more and more as standard procedure and ensure reliability of the castings. A solid frame construction is stressed up to a maximum of 6 tons/sq. in. under maximum jamming conditions. Now the guiding of the ram is achieved by a separate top and bottom guiding system, the upper guide being disposed well above the line of the main eccentric. From the eccentric a direct line of thrust extends through a heavy pitman and a pitman end which runs in a large bearing segment on the main ram (fig. 7). In my view it is unwise to apply the thrust through a gudgeon pin and small-diameter bearings with an extremely limited thrust area. At the bottom of the stroke extremely heavy pressures arise and it is, therefore, necessary to reduce the pressure loading on any bearing areas as low as possible in order to maintain the oil film.

When making a comparison between one forging press and another it is advisable to study most carefully the diameters of eccentric journals and ensure that these large working areas are maintained in contact. In order to preserve this oil film it is necessary to design the drive with a continuously smooth action, avoiding any overrun and maintaining clearance faces in close contact. The pitman and its very heavy ram can tend to overrun the drive towards the bottom of the stroke, giving in

effect a momentary double blow when meeting resistance. This double blow effect is detrimental in two ways; firstly it enables heat to be lost from the workpiece before the main pressure starts to be applied, secondly it causes the oil to be forced away from the working faces due to the knock that is introduced. A modern development is dynamically to balance the ram in such a way that its acceleration is compensated by a pneumatically counterbalancing system in which the counterbalancing load increases as the ram advances down its stroke and thereby maintains it continuously in contact with the thrust face of the pitman. The balancing force required to maintain this contact can be up to twice that required for static balance.

Maintenance and life

It is appreciated that maintenance on the forging press must be reduced to the minimum, that is, the day-to-day or week-to-week maintenance. Any overhaul on a forging press is likely to be an expensive and possibly lengthy operation. This machine should go on working day and night and continue for several years without major replacement. It is then reasonable to undertake a *major* overhaul, in which journals, slides and clutch can all be repaired at the same time, while the press is down. However, the life of the mechanical parts, and in particular the bearings, on double or treble shift working, day in, day out, and frequently for several years, can only be achieved by an automatic lubrication system which delivers a more than adequate supply of oil, and is for preference duplicated in system to ensure that in the event of failure for any reason a secondary supply is automatically available. Otherwise a seizure can quickly take place before the warning signal of failure of the main supply is noticed and the press is stopped. My company has done a considerable amount of work in this direction and we cannot sufficiently stress the importance of an adequate and foolproof lubrication system being applied to this type of machine.

7 *Pitman and ram assembly*

I would mention the importance also of reducing the inertia of moving parts as far as possible. For this reason it would seem important to have the clutch drive mounted on the main eccentric shaft. Our experience is that if the clutch is mounted on a high-speed shaft with intermediate gearing then there is the danger, in an inadvertent case of jamming, of the energy stored up in the intermediate gearing to continue to drive the eccentric shaft through a few further degrees of movement which could lead either to a fractured frame, or which could impose exceptional stresses on the frame, or lead to a more serious jam up which would be impossible of release and which would certainly be beyond releasing capacity of the drive.

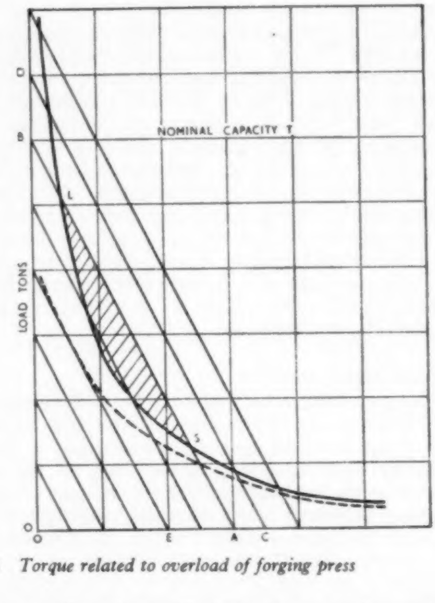
Fig. 8 shows a typical ' load against distance from bottom of stroke ' curve based on a constant torque capacity which would be representative of any make of forging press in which an eccentric or crank provides the reciprocating movement. The area enclosed between this curve and the axis represents the energy which can be put into the forging and frame before clutch slip will occur. The angular lines *A-B* and *C-D* are those of the frame load elasticity and represent the extension of the frame, the contraction of the dies, the bolster, the oil films between ram, connecting rod and so on, for various distances from the bottom of the stroke. Assuming a press of nominal capacity of *T* tons, to utilize the full capacity of the press the load should rise finally along or touch the line based on *E*. Now, if, for a number of possible reasons, for example, the temperature of metal, maladjustment of tools, the load should commence to build in the final stage on line *A*, slipping of the clutch will occur where its torque capacity is exceeded at intersecting point *S*. However, the inertia of the eccentric, clutch and clutch parts which are continuing to rotate, carry on until the amount of energy stored in them, which is represented by the shaded area between the curve

and the line *LS*, is sufficient to bring the eccentric into a position where the clutch torque at point *L* becomes more effective, where slip discontinues and the available torque is capable of turning the eccentric further to take the press load to point *B*.

I should mention that the diagram is approximate only and that at point *S* the slipping of the clutch is dependent on static friction and at point *L* on dynamic friction, and the shape of the torque curve is affected also by any increase in bearing friction in the press. However, the diagram serves to show that, for high-speed presses, it is essential to keep the inertia of the intermediate clutch, brake and transmission members to an absolute minimum and for this reason to arrange, if possible, for them to be mounted on the eccentric shaft. In this way the drive can be so arranged that overload and, consequently, jamming protection can be provided by clutch slip and, should a jam occur, metering up the air pressure in the clutch provides adequate drive to disengage, at least in reverse, from the tool-down position.

We have carried out practical tests to ascertain the load imposed on a solid-frame press under the worst jamming condition. To arrive at this we employ a lead blank placed between the dies, the clutch is engaged and the ram driven downwards to a position at which slip commences in the clutch. At this point the lead is squeezed to a thin plate across the face of the dies. The point at which this occurs is indicated by a modified 'Desyn' test apparatus, the transmitter of which is connected to both sides of the clutch drive, so that immediately slip occurs a current is generated and the differential motion indicated on the receiving dial. At this point the load is checked against a carefully calibrated extensometer on the press frame. This has demonstrated a stress from two to three times the nominal stress of the frame at 2 tons/sq. in., so that even under the most dangerous condition the frame is only stressed up to a maximum of 6 tons/sq. in. The lead is then melted out, thereby easily releasing the load. However, in the event of a jam up it is important to release the press members from it as quickly as possible. As long as the high pressure is being applied the lubricant is being squeezed out of the various journal surfaces between pitman, ram and eccentric, making the job of releasing from this state more difficult the longer it is delayed. If, as I have mentioned earlier, the jam up is not severe, it can easily be overcome by increasing the air pressure to the clutch which is designed to run at a lower than normal pressure for this very purpose.

Assistance towards relieving a jam up can be given by careful attention to the design of the wedge adjustment of the bottom bolster. We have found that a taper of 1 in 4 adequately meets this situation, for it corresponds to an angle somewhat



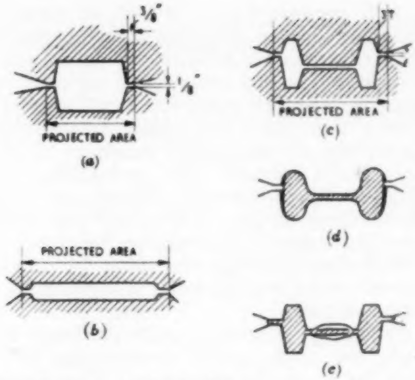
8 *Torque related to overload of forging press*

greater than the angle of friction on surfaces under conditions of semi-lubrication and unit pressure-loading most likely to be experienced in this application. When considering the frictional resistance to withdrawal of the wedge there is both the frictional resistance of the horizontal face as well as the inclined face to be taken into consideration.

With regard to the clutch drive, it is, of course, important that the ram is brought to rest consistently at the top of its stroke and the use of the smallest volume of air in actuating the clutch, and consequently requiring to be exhausted, contributes to the engagement and disengagement rate of the clutch. Owing to the heat generated, it is also useful to arrange, as far as possible, for an adequate supply of cooling air to circulate over all friction surfaces and on a machine in which the clutch can be operating many times per minute, it is important to protect the splines from the continuous hammering effect which can arise from the loose location of the outer clutch plates and the piston and plate. Return springs holding these plates against cone seatings have been introduced to obviate this.

Loading of forging presses

I have referred to the stop and start positions of the controls. In this respect variation in temperature, particularly between the beginning and middle of a shift, can affect the freedom of running of the press, and in the most modern design an over-running control is fitted which enables the operator



9 *Loading examples for forging press*

to make a fine adjustment either to advance or retard the position of the ram at the top of its stroke. Forging presses are fitted with a load indicator calibrated to show the load being applied and useful as a test of the load required for a specific component.

Fig. 9 gives a rough guide to the loading of a forging press. The load may be taken as the product of the average unit pressure loading and the projected area of the forging against the die including the contact area of the flash. However, the unit pressure loading in tons per square inch can vary considerably according to the location in the die area, the thickness of the metal at the location, the temperature of the workpiece of the dies and the allowance for the thickness of flash. It is, therefore, extremely difficult to establish a formula which would take into account all these values. However, for typical forging shapes the following average figures would form a rough guide. I am assuming that the material to be forged is a carbon or low-alloy steel with a working temperature of 1,150–1,200°C. and a fin of approximately $\frac{1}{8}$ in. thick. Any thinner flash than this would increase the load figures considerably. This would also apply to inadequate temperature of the forging or cold dies. It is a recognized practice to heat the dies to a reasonable temperature before use and to maintain them at that temperature artificially, if the volume of work being dealt with is not sufficient for the purpose. I would here mention that electrically heated dies are not uncommon, and I believe they could be more extensively employed. It is assumed that the width of the die area around the forging is about three times the thickness of the flash. A very wide variation in the average pressure loading exists between the chunky piece in fig. 9 (*a*) and a forging with a thin confined central area as in fig. 9 (*c*). This loading varies from 25–70 tons/sq. in.

For smaller areas than fig. 9 (*a*) the pressure could be lower, possibly 22 tons/sq. in. For larger diameters up to, say, 10 in. dia., the pressure could increase to 25 or 30 tons/sq. in., the resistance to lateral movement being increased by the longer path of resistance. Fig. 9 (*b*) is a thin forging of large area with an average pressure loading of 50–60 tons/sq. in. Temperature is quickly lost due to the low volume, and therefore high pressures are incurred, dependent upon the area and the thickness. In fig. 9 (*c*) the pressure in thin confined central area can be very high, up to, say, 70 tons/sq. in. or more, and it is necessary to assume a higher *average* pressure than in fig. 9 (*a*). Obviously, the average will depend to a large extent on the proportion of thin central area to the total area. A crown wheel, for example, with a diameter including flash of, say, $8\frac{3}{4}$ in., 55 sq. in. in area, would require an average pressure of 40 tons/sq. in. in the finishing die if formed in one stroke. This loading can, however, be considerably reduced if the piece is pre-formed as shown in fig. 9 (*d*). Here the central area is forged down to approximately the final flash thickness, but the outer ring is only roughly formed to shape without making flash on the periphery. In this way, while the pressure in the central area is high, it is associated with a low intensity on the outer ring, thus reducing the average. In the finishing die, fig. 9 (*e*), where the full load comes on the exterior ring, the load in the centre area is minimized, the dies being relieved in the middle to allow for a small amount of metal to flow inward. Although there will be a certain amount of heat loss in the pre-forming operation, the load generated in the finishing dies can be reduced considerably as compared with that resulting from making the forging in one stroke. This, of course, involves two separate impressions. I should mention that normally it is desirable to move the material in one uninterrupted stroke and no reduction in the maximum pressure load is gained by using two strokes on a forging in the same die. Even pre-forming in dies of different shape should be used with care and the cooling effect of the pre-forming stroke may increase the pressure loading in the final impression, so that it would have been preferable to forge the piece in one blow.

Forging press and screw press compared

I would like briefly to refer to one or two points in making a comparison between a forging press and a screw press. It should be understood clearly that there are two factors to be considered in regard to press loading. Firstly, energy load; secondly, pressure load. A preliminary forming operation involving a considerable movement of metal can require a large amount of energy although at the completion of the stroke the pressure may be well

below the nominal capacity of the press. On the other hand, the final pressing operation in the finishing die which results in very small deformation of material can require the full pressure capacity of the press and yet demand only a very small amount of energy.

In the screw press, energy is put into the flywheel through rotational contact with driving discs and all this energy is expended in the forging stroke, part being absorbed by the forging and the surplus as spring energy in the frame and other sections of the elastic circuit. To avoid overstressing the screw press, the flywheel speed has to be limited by presetting the power stroke to give an energy output just slightly in excess of that required to forge. If the control is set to give the requisite amount of energy for a heavy preliminary forging operation, the pressure developed could be well within the nominal capacity. If, however, the same energy control setting is used in a finishing stroke in which the vertical deformation is small, the pressure developed could be very much greater than that for which the press was designed. The converse is also true, that if the power stroke is set to the low energy rating to suit the finishing operation, the screw press could give the full-rated pressure at this stage, but when used at this energy setting for the *preliminary forming*, the ram would be found to stop short, the screw press having insufficient energy and pressure to complete the stroke. The eccentric press has the advantage in that it can give automatically within its maximum capacity, energy and pressure as dictated by the forging irrespective of the vertical deformation.

The pressure load in forming the majority of pieces usually builds up very rapidly close to the end of the stroke, and therefore the major part of the stretch develops coincident with the maximum heat transfer. It is the effect of this degree of elasticity on the dwell time that the solid-frame design contributes as against the tiebolt arrangement. It is sometimes said that an oversize piece put into the normal drop-forging dies in an eccentric-type press could create a serious pressure overload and, in consequence, it is necessary to control carefully the size of the workpiece. This is contrary to the facts. It has been demonstrated that when pieces at the same temperature are 50% and even 100% greater volume than that of the forging have been placed in an eccentric forging press the pressure loads are actually less than that which obtains for a piece of correct volume. The reasons for this are as follows: firstly, a greater initial heat content by virtue of the greater volume; secondly, more heat is generated within the workpiece because of the greater energy required for deformation; thirdly, the early establishment of an elevated temperature of the die surface resulting in less chilling effect in the final pressure stage. It will, of course, be understood that the dies used in such a test are a normal type from which excess material can run out at the joint line and which have sufficient relief beyond the flash line to take the excess metal.

I have, in the course of my paper, drawn attention to a number of fundamental constants which require careful thought and investigation when making a comparison between one type and one size of machine and another. These are problems which every manufacturer of forging plant has to face, and the differences in design stem from the degree of emphasis which one particular manufacturer puts on any one point.

Developments in forging plant inevitably move slowly, and ideas, sound theoretically, are not always borne out by experience. The trial of a change of design in a drop hammer can only show confirmed results after a long and comprehensive test under arduous and versatile conditions.

High-vacuum metallization

The first comprehensive range of metallized materials to become available from a company engaged mainly in the packaging, converting and allied fields, has been introduced by E. S. & A. Robinson Ltd. (Redcliffe Street, Bristol), after more than 10 years of investigation, and two years of intensive research and development.

Early last year Robinsons installed a high-vacuum metallizing plant in Bristol and intensified their previous research work into high vacuum metallization and into the pre- and post-treatments of a wide range of materials for processing under this technique.

Metallization is the technique of depositing a thin layer of aluminium or other metal on the surface of a material—p.v.c. film, paper, etc.—under critical conditions of vacuum.

Metallized materials will probably be competitive with ordinary foil for some purposes, but there are many other uses to which such materials will be put, particularly where the material itself has certain characteristics, such as protective qualities, which can be used to enhance the inherent advantages of foil.

Wiggin alloys

Henry Wiggin and Company announces new names for certain high-nickel alloys. This re-naming has become necessary because of the wide diversity of compositions which have been developed over the last few years to meet specific material requirements.

INCOLOY DS is the new name for the alloy previously known as NIMONIC DS. This is essentially a nickel-chromium-iron alloy, useful in oxidizing conditions at temperatures up to 950°C. Originally developed for wire-woven conveyor belts for furnaces, INCOLOY DS is increasingly used for furnace parts and a wide range of other high-temperature equipment.

VALRAY 1 is the new name for BAC BRIGHTRAY, an 80/20 nickel-chromium alloy used extensively for the coating of automobile exhaust valves. VALRAY can be applied either as a protective coating to the valves during manufacture, or it may be used to reclaim valves which have burnt out.

C-Au-C and C-Pt Pd-C extraction replicas for electron microscope analysis

IVAN HRIVŇÁK

The method of preparation of C-Au-C and C-Pt Pd-C extraction replicas for electron microscopy and electron diffraction analysis is described. By comparison with carbon extraction replicas, these replicas have the advantage that it is possible to obtain unlimited contrast, and thereby utilize the full power of resolution of the microscope. The method is universal, and, subject to certain modifications, may be applied to all metals. These new replicas may suitably supplement the C-Pt replicas of Bradley. This is the first publication of an original article written in Czechoslovakian and translated by M. de O. Tollemache. The author is with the Welding Research Institute in Bratislava, Czechoslovakia

THE USE of carbon extraction replicas prepared according to the methods of Bradley[1] and Smith and Nutting[2] has had great importance in the study of metals by means of electron microscopy and electron diffraction.

These replicas have made possible not only the extraction of the precipitating phases, but, thanks to their extremely good power of resolution, they have also enabled the morphological configuration of these particles and their relationship to the matrix to be studied.

But carbon extraction replicas have had a certain disadvantage in that there was little contrast of the specimen mainly during the study of poorly defined phases such as martensite bainitic structures, the surface structure of austenite, or slip planes on a deformed surface and similar effects. This inadequate contrast may be obviated by numerous methods. One of the methods is the vaporization of a carbon film *in vacuo* on to the polished surface tangentially at an angle of 30–45° at a high underpressure of 2×10^{-5} mm. Hg.

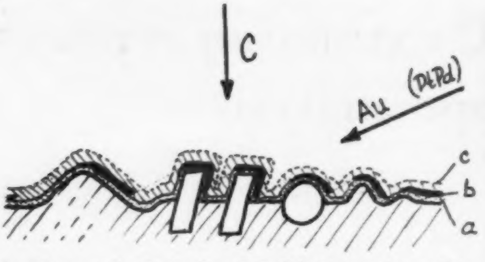
Bradley obtains increased contrast by using for this tangential vaporization not carbon electrodes, but a combination of a flat carbon and a pointed C-Pt electrode, so that a C-Pt film is vaporized on to the polished surface.[2] This method has optimum application, and perhaps its sole disadvantages are on the one hand the limited possibility of thinning down the replicas and of creating contrast, and on the other hand its unsuitability for diffractographic study, since the lines of the subject of diffraction are covered with the lines of the Pt.

An increase in the contrast of a carbon extraction replica by shadowing its negative side with chromium, for instance, is not a suitable solution, since the coarseness of the replica is increased, which implies a drop in the power of resolution, and also because artefacts can occur. A carbon film also has the disadvantage that during drying it shrinks and splits. Thus it may happen that the original spatial formation loses height and is elongated in the direction of the plane of the film. Through the shadowing of this film artefacts arise, since spatial specimens lose height and increase their dimension in the plane of the replica.

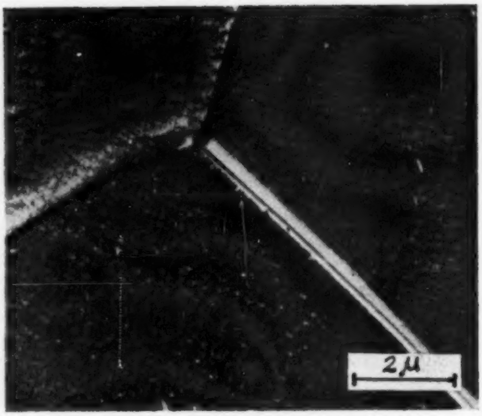
In the following text a description is given of a new possible method of increasing the contrast of carbon extraction replicas without lowering their power of resolution. This is the method of single-stage positive, C-Au-C or C-Pt Pd-C extraction replicas, which suitably supplements the C-Pt replicas of Bradley. The advantage of the newly modified replicas is the possibility of obtaining unlimited contrast dependent on the type of structure discovered, as well as the possibility of employing these replicas for electron diffraction, if part of the surface is blanked off with a screen before vaporizing with Au or Pt Pd.

Method of preparation

C-Au-C, or C-Pt Pd-C replicas may be used for all metals, including not only unalloyed steels but also austenitic alloy steels, special alloys of the Nimonic type, etc., non-ferrous and light metals and their alloys. This method can likewise be used



1 *Diagram of a C-Au-C or C-Pt Pd-C extraction replica:*
(a) basic layer of carbon, about 10^1 Å *thick;*
(b) shadowing with Au or Pt Pd;
(c) carrier layer of carbon



2 *Boundaries of ferritic grains. Etched 2% HNO_3. C-Au-C replica. Reduced from ×10,000 on reproduction*

for the study of fracture surfaces of the materials mentioned.

During the development of the method, a start was made from the assumption that the polished surfaces to be studied with the electron microscope are prepared electrolytically, which reduces the time required for the preparation of the surface to a few minutes, and that it is not, therefore, necessary to prepare several replicas from a single polished surface.

The polished surface is prepared by the normal metallographic technique, and after the revelation of the structure it is washed in alcohol, acetone and benzene. If only a morphological study is to be made, collodion cleaning replicas may be used for better cleaning of the surface. The preparation of the C-Au-C or C-Pt Pd-C extraction replicas is as follows:

First of all, a thin layer of carbon, about 10 Å thick, is vaporized on to the surface at right angles; this covers all the structural particles with an approximately even layer of carbon (fig. 1 (*a*)). This layer is necessary for the separation of the layer of Au or Pt Pd from the metal surface.

Then gold or Pt Pd alloy is vaporized on to the surface obliquely at the required angle, thereby creating a positive contrast (fig. 1 (*b*)). The angle of vaporization and the quantity of metal vaporized on to the surface are dependent on the morphological configuration of the structure.

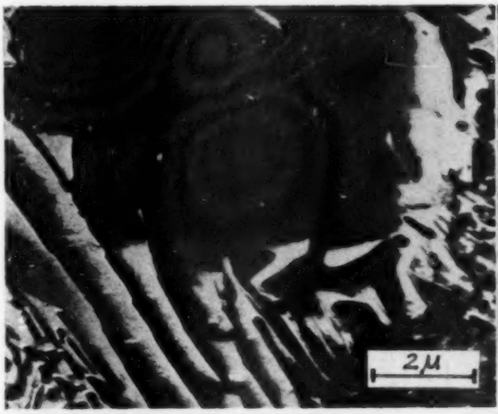
Finally, a carrier film of carbon is vaporized on to the surface, once again at right angles; this ensures the stability of the replica (fig. 1 (*c*)). The thickness of this film is about 100 Å, such that the total thickness of the replica shall not be greater than 200 Å. The C-Au-C or C-Pt Pd-C film is cut up on the surface of the polished specimen into small particles, and separated from the metal surface in a 10% solution of HCl in alcohol. For unalloyed and low-alloy steels the time of dissolution lasts about a few minutes. For alloy steels it is preferable to separate the replicas electrolytically in the HCl solution at a voltage of 6 V., using the specimen as the anode.

Applications

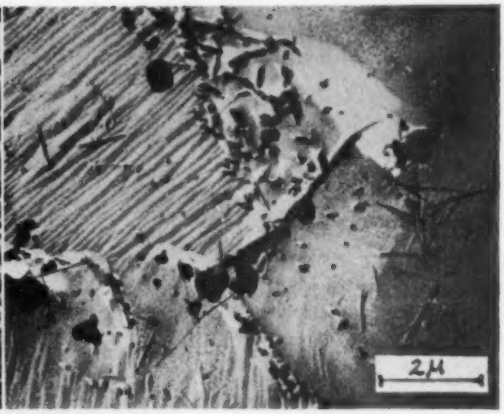
The use of carbon extraction replicas for commercial carbon steels gives good contrast with the pearlite, whereas the ferritic grains and the ferritic grain boundaries have such a small degree of contrast that it is impossible to investigate their structural orientation. In figs. 2 and 3 are shown two examples of the use of C-Au-C extraction replicas for low-carbon steel No. 1, the chemical composition of which is given in Table 1. The replicas were separated from the polished surface by the chemical action of 10% HCl for a period of 15 min. In fig. 2 may be seen the junction of three grain boundaries. It may be shown from this illustration that, as a result of etching with nital, the boundaries of the ferritic grains stand out above the level of the ferritic grains themselves. Through the effect of the shadowing it is possible to distinguish

TABLE 1 *Chemical compositions of the steels investigated, %*

	C	Mn	Si	P	S	Ni	Cr	V	Mo	Nb + Ta	W	Ti	Cu
Steel No. 1	0·2	0·93	0·27	0·03	0·02	—	0·17	—	—	—	—	0·05	—
Steel No. 2	0·09	17·5	0·62	traces	0·025	traces	7·4	—	—	—	—	0·36	—
Steel No. 3	0·04	0·92	0·1	0·016	0·016	12·5	16·3	1·0	1·3	0·64	—	—	0·11
Steel No. 4	0·055	0·7	0·1	0·015	0·015	12·8	16·3	—	—	—	3·9	0·1	0·3

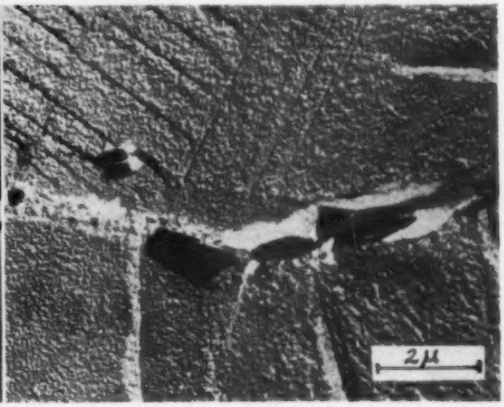


3 *Ferritic-pearlitic structure. Etched 2% HNO_3.*
C-Au-C replica. Reduced from ×10,000 *on reproduction*



4 *Precipitated carbides in austenite.*
C-Pt Pd-C replica. Reduced from ×10,000 *on reproduction*

5 *$M_{23}C_6$ and NbC carbides and σ-phase with subgrain structure in austenitic steel.*
C-Pt Pd-C replica. Reduced from ×50,000 *on reproduction*

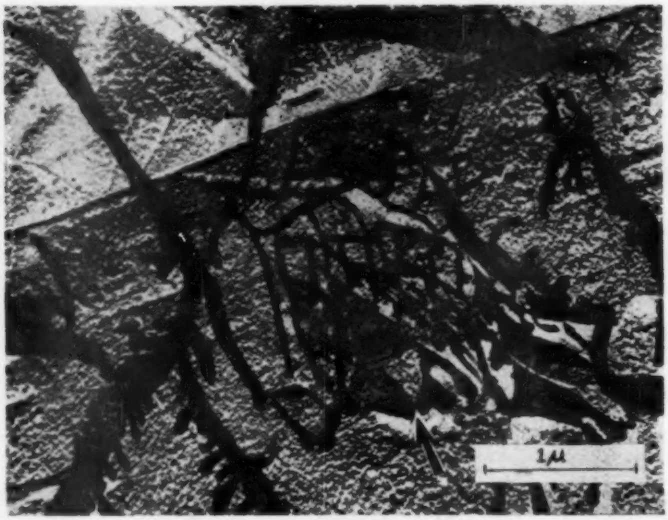


6 *Grain boundaries with $M_{23}C_6$ carbides in* 17 *Mn-*7 *Cr steel. Electrolytically etched in* 10% *HCl.*
C-Au-C replica. Reduced from ×10,000 *on reproduction*

not only all the precipitates, which are indicated by the small arrows, but also their relationship to the matrix. In fig. 3 is portrayed the interface between an island of pearlite and the matrix of ferrite. That part of the pearlitic cementite, which had a suitable orientation with reference to the polished surface of the specimen, was extracted in the replica. The difference in contrast between carbon extraction replicas and C-Au-C replicas can also be seen from this illustration, if a comparison is made between the shadowed and unshadowed areas.

Figs. 4 and 5 are typical examples of the use of these replicas for austenitic steels. Fig. 4 represents the extracted particles of the carbides $M_{23}C_6$ and NbC along the grain boundaries and within isolated grains. The specimen was electrolytically etched in 10% HCl solution, and the contrast of the matrix through the effect of shadowing with Pt Pd is sufficient to obtain a good power of resolution. This material of the 16 Cr-13 Ni type, the chemical composition of which is given in the table as steel No. 4, was homogenized for 4 h. at 1,100°C. and heat treated at 800°C. for 800 h.

Fig. 5 relates to the 16 Cr-13 Ni material, designated in the table as steel No. 3, which was homogenized for 4 h. at 1,100°C., and then heat treated at 800°C. for 100 h. and at 700°C. for 800 h. By X-ray analysis we established the presence of the carbides NbC and $M_{23}C_6$ and of the σ-phase in the structure. Through the effect of the subgrain



7 Bizarre formation of an $M_{23}C_6$ carbide in 17 Mn-7 Cr weld metal. Attention is drawn (by the arrow) to the extinction of the contour(s) in the thin part of the carbide. Electrolytically etched in 10% HCl. C-Au-C replica. Reduced from ×40,000 on reproduction

structure, the σ-phase is very clearly visible in fig. 5. In this phase are extracted residues of $M_{23}C_6$ carbides, as was shown by selective electron diffraction.

The structure of 17 Mn-7 Cr austenitic steel, the chemical composition of which is shown in the table under steel No. 2, is characterized by fig. 6. This is the junction of three grains with precipitated $M_{23}C_6$ carbides. Carbides of this type form pronounced dark marks (dendritic shapes) in weld metal, as is evident in fig. 7 which shows the same material. Special attention should be devoted to the extinction of the contours in the thin area of the carbide, which represent the presence of dislocations.

Acknowledgments

The author wishes to thank K. J. Malík for providing experimental materials Nos. 3 and 4, and Dr. V. Drahoš, of the Electron Optics Laboratory of the Czechoslovak Academy of Sciences in Brno, for collaboration in the production of certain of the microstructures in the new Czechoslovak electron microscope with a high power of resolution.

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(1) *British J. Appl. Phys.*, 1954, **5**, (2), 65; *Ibid*, 1954, **5**, (3), 96; *Nature*, March, 1958, **181**, 875, or *British J. Appl. Phys.*, May, 1959, **10**, 198.

(2) *British J. Appl. Phys.*, 1956, **7**, (6), 214.

Iron and Steel Institute

The autumn general meeting of the Iron and Steel Institute will be held at Church House, Great Smith Street, London, S.W.1, on November 29 and 30, 1960.

The technical sessions will comprise two symposia, on 'Fluid flow in furnaces and converters' and on 'Martensite' respectively, which will run concurrently.

Mr. L. Rotherham, Member for Research, Central Electricity Generating Board, will deliver the 13th Hatfield Memorial Lecture at Church House on the evening of November 29. He will take as his subject 'The contribution of metallurgy to electric power generation.'

Admission will be by ticket only.

Following the AGM, the Institute is holding a symposium on 'Steels for reactor pressure circuits' from November 30 to December 2.

Steels with improved abrasion resistance

Two new austenitic manganese steels which provide improved abrasion resistance in castings have been developed by Climax Molybdenum Company, a division of American Metal Climax, Inc.

One of these steels is a 12-2 manganese-molybdenum alloy which combines toughness and abrasion resistance with a high degree of ductility. The other is a 6-1 manganese-molybdenum alloy which has exceptional abrasion resistance but only moderate ductility.

In both of these steels, molybdenum makes possible the use of higher carbon contents than is normal in Hadfield manganese steels. Where 1·25% carbon often causes embrittlement, the globularizing of carbides in grain boundaries by molybdenum makes possible the use of as much as 1·7% carbon in commercial castings.

Climax has found the new steels particularly valuable in its own mining operations. The 12-2 alloy is being used successfully in slusher scrapers and cone liners. It has demonstrated up to 40% longer life and resistance to flow than Hadfield manganese steels. The 6-1 alloy shows promise for applications such as grinding mill liners and scoop lips, screen decks, grates and jaw crusher liners.

The company does not plan to market these steels commercially but will make its research and development information available to interested companies upon request.

Metallurgy in nuclear power technology

5. Fuel element canning materials—part 1

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles which are appearing monthly in this journal

It is evident from the physical, corrosion and mechanical properties of natural uranium and the influence of irradiation that it cannot be relied upon to fulfil all of the working reactor requirements economically without resorting to some form of container to carry part of the structural load, prevent corrosion, restrain the element from altering its dimensions and prevent loss of fissionable or fission product particles.

The properties required in a canning material are: (1) It must be a metal or alloy of low neutron capture cross-section which can be fabricated and welded. (2) It should have a reasonable high temperature strength. (3) It should be compatible and stable with respect to the fuel and the coolant. (4) It should have adequate thermal conductivity.

Probably the most important consideration is that of having a low neutron capture cross-section; but the requirements for thermal reactors differ from those of fast reactors. The requirement for low cross-section to thermal neutrons limits the choice of materials to those having a thermal neutron capture cross-section of less than 1 barn and preferably less than 0·1 barn. It is possible with fast neutron reactors to allow a wider range of materials.

Consider now some of the properties of possible canning metals. Aluminium was the first metal to be used for sheathing uranium because, of the metals of low neutron capture cross-section, it was the most readily available commercially and its fabrication and welding technology was widely appreciated. It possesses certain disadvantages which will be discussed under the heading of the physical properties of the canning materials, and was superseded in several reactor applications by magnesium and a few special alloys of magnesium. Here again the extraction and fabrication of magnesium is fairly widely appreciated so remarks will be confined to those properties of special interest to reactor technologists.

Other materials of interest as possible canning materials are nothing like so common as aluminium and magnesium and all aspects of the metallurgy of, for instance, zirconium, beryllium and niobium have received very considerable attention as a result of their application in power reactors. Since it is not only relatively new but also affects the economics of the metals considerably, the extraction and fabrication technology of some of the newer canning materials will be reviewed.

Canning methods may be grouped in three categories: (1) No bond between fuel and can. Only very low heat extraction rates are possible with this system. (2) A solid metallic bond between fuel and can. This allows good heat transfer and tends to inhibit growth. (3) A liquid bond between fuel and can. Again this allows good heat transfer but does not restrain the fuel.

Fuel may be clad by plating, hot dipping or

Table 11 *Analysis of niobium powder and sheet rolled from sintered bar (from O'Driscoll and Miller, 'J. Inst. M.,' April, 1957, p. 384)*

	Powder weight %	Sheet weight %
C	0·25	<0·01
O	0·50	0·05
N	0·07	0·01
Ta ..	0·30	0·30
Si	0·08	<0·01
Fe ..	0·05	0·05
Pb ..	0·10	0·005
Ti ..	0·05	0·05
Sn ..	0·08	0·08

metal spraying, but these are not used extensively. Cans may be produced by extrusion, normally followed by cold or warm drawing; by impact extrusion and by various methods whereby the canning is created integrally with the fuel element.

Impact extrusion makes use of a press such as a 200-ton capacity crank or flywheel inertia press to extrude the tube over a mandrel set in the centre of a die. In this way longitudinal fins can be set on the tube in the same operation. By setting the die segments at an angle, it is possible to produce a spirally-finned tube. It is easier, to ensure uniformity, to impact extrude a straight-finned tube and then twist the complete assembly. Two other extrusion methods are normal extrusion over a mandrel or extrusion through a porthole die in which a mandrel plug in the centre of the die is held by a spider round which the alloy flows in three streams to reunite in a restricted annular section beyond the die. Another method of finning is the 'Integron' High-fin process in which the fins are extruded outwards from the wall of a tube by rotary forming.

The commonest method of sealing cans is to machine away the fins for a short distance at both ends of the required length, to machine a slight recess in the ends and insert an inverted cap into each end. The joint between the cap and the can wall is then Argonarc welded. This may be followed by tucking the weld into the centre of the recessed cap and filling the cap with brazing metal.

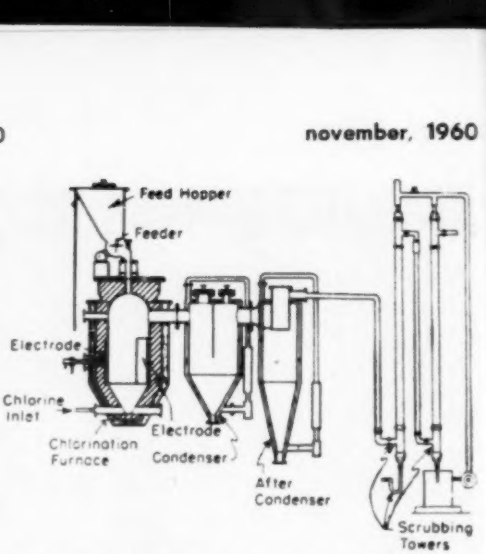
Integral canning from a built-up powder billet is possible. The billet is made up from alternate layers of fuel and canning material fitted into an outer container of canning material. Co-extrusion is carried out and the extruded product consists of integrally-canned fuel separated at appropriate intervals by canning material over the whole cross-section. The extruded bar can be parted at these points. This type of fabrication could be employed for fuel having a non-uniform distribution of alloying element.

Integral canning may also be achieved by rolling, but at present this is only successful with the flat plate type of element.

ZIRCONIUM

Extraction procedures

There are numerous zirconium-bearing minerals as might be expected from the fact that zirconium is not a rare element in the earth's crust and is widely dispersed. It is about the tenth most abundant metal and is more abundant than zinc, copper and lead for instance. It is the comparatively difficult process required to isolate the metal from its ores which has previously grouped zirconium with the so-called rarer metals. In fact, the world reserves of zirconium are immense. Of the many zirconium minerals, only two are used commercially for the isolation of the metal: zircon, the silicate of zirconium $ZrSiO_4$, and baddeleyite, the native oxide ZrO_2. Australia and the U.S.A. are the two leading zirconium ore producers, with other sources in Brazil, Ceylon, Africa and Malaya. The richest deposits are zirconiferous sands formed as a result of weathering of granite. The sands also contain rutile and ilmenite, both sources of titanium, and monazite which is a mixed phosphate of cerium and rare earths.



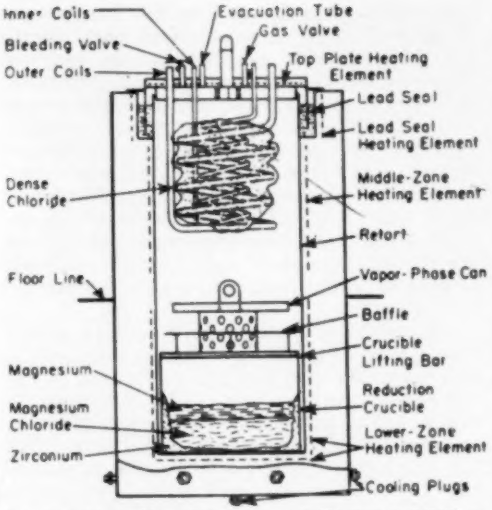
24 *Direct chlorination unit (Shelton and Dilling, Zr and Zr alloys, ASM, 1953)*

All zirconium minerals contain hafnium which must be separated from zirconium for nuclear reactor purposes because of the very high neutron capture cross-section of hafnium. Zirconium contaminated with hafnium would be useless as a canning material in thermal reactors because of the adverse effect on neutron economy. On the other hand, hafnium is a valuable neutron absorption control material and is therefore worth concentrating for this reason. Both zircon and baddeleyite can contain up to 2% of hafnia.

Concentration of zirconium minerals

The zircon sand associated with rutile, ilmenite and monazite is heavier than quartz, which is the major diluent. The richest sections of the sands are stripped and passed over Wilfley tables. The table concentrate is then passed through electrostatic or electromagnetic separators and the resulting concentrate averages 93–99% zircon. Other streams of the concentration plant produce a very rich rutile concentrate and a mixture of zircon and rutile together.

Prior to the 1950s, zirconium technology was almost entirely concentrated on ceramics, refractories, special foundry sands and zirconium master alloys. Very little zirconium metal was isolated,



25 *Assembly of Mg reduction furnace (Shelton and Dilling, Zr and Zr alloys, ASM,* 1953)

particularly hafnium-free zirconium. Consequently, there are several routes by which zircon and baddeleyite may be decomposed, prior to consolidating the metal. Basically the problem is to separate the silica and zirconia from zircon. Silicon may be volatilized away by heating zircon at about 2,000°C. in the presence of carbon, the silicon volatizing as silicon monoxide. Various fluxing treatments include caustic soda, nitre cake, potassium bisulphate, sodium or potassium fluorides and calcium oxide/chloride mixtures. After fluxing, the resultant cake is leached and appropriate zirconium salts precipitated from the leach liquor.

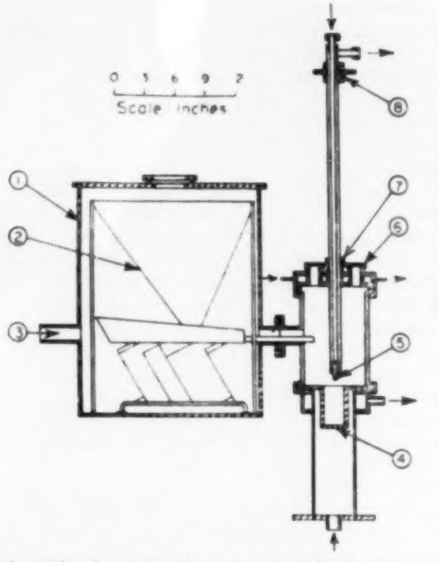
The main commercial route, ending with the Kroll process, takes zircon sand and carburizes this with coke breeze in an electric arc. The furnace consists of a steel shell lined with silicon carbide and the working zone within this is a graphite crucible. The crucible is charged with the sand/coke mixture and a graphite electrode is lowered into it to form an electric arc. After the reaction, about 90% of the zirconium has been converted to zirconium carbide and about 95% of the silicon has been volatilized as SiO. If air is allowed to reach the reaction process the zirconium forms carbonitride which may also be processed for zirconium. The carbide or carbonitride is then chlorinated in a vertical shaft furnace (fig. 24), about 8 ft. high and 3½ ft. in diameter, to which is attached a condenser. The carbide or carbonitride is charged on to a bed of hot coke on the hearth of the furnace and chlorine gas is admitted beneath.

Once started, the reaction can proceed for long periods and being exothermic it is only necessary to feed crushed carbonitride continuously in at the top of the furnace and chlorine from below. Zirconium tetrachloride is formed and is passed to a condenser maintained at 100°C. This ensures condensation of the zirconium tetrachloride to a solid of variable compactness, but silicon tetrachloride and titanium tetrachloride are not condensed and are taken out with the waste gases.

Hafnium is still associated with the zirconium at this stage, together with traces of iron, chromium, silicon and zirconia. The shell of the furnace and of the condenser is usually of nickel, which will withstand chlorine and other corrosive effects of the reaction. The furnace may be lined with silica or with graphite, but the condenser is a heated unlined nickel shell.

For nuclear energy applications the zirconium tetrachloride has to be freed from hafnium at this stage. There are several ways of doing this. The tetrachlorides may be dissolved in dry commercial alcohol and separated by preferential absorption on silica gel. Fractional distillation of the tetrachlorides is possible or fractional recrystallization of a salt such as K_2ZrF_6. The end-product of the hafnium separation process is generally zirconium oxide which must be converted back to the tetrachloride by treatment with carbon tetrachloride, or by heating with carbon and chlorine gas. The latter process is very similar to one used for the production of magnesium chloride from caustic magnesia. The zirconia is mixed with carbon and briquetted. The briquettes are fed to a chlorinator where they are heated by their resistance to the passage of current from three graphite electrodes. Gaseous chlorine is fed in at the bottom of the chlorinator and the zirconium tetrachloride is condensed in an air-jacketed nickel condenser.

The zirconium tetrachloride is reduced to sponge zirconium metal by the Kroll process which uses molten magnesium as a reducing agent. The reaction chamber (shown in fig. 25) contains pure magnesium and solid zirconium tetrachloride and is flooded with an inert atmosphere during the reaction. The chamber may be heated in sections. Thus it is possible to first melt the magnesium and raise its temperature above the melting point of $MgCl_2$ while water-cooling the solid zirconium tetrachloride which would otherwise volatilize at 331°C. before the magnesium is molten. The zirconium tetrachloride is then allowed to vaporize and the vapour reacts with the molten magnesium. The reaction creates zirconium, which condenses in sponge form on the bottom and lower sides of the vessel, and magnesium chloride which contaminates the sponge. After reduction of the zirconium tetrachloride the



26 *Assembly of tungsten-electrode arc melting furnace*
1 Steel feed tank 2 Feed hopper 3 Vacuum line 4 Copper mould cup 5 Electrode 6 Eyepiece 7 'O' ring gland 8 Power connection

reduction vessel and its contents are cooled under an inert gas atmosphere. The sponge is removed and contains, in addition to zirconium metal, magnesium chloride and magnesium. The contaminants are removed by heating the sponge *in vacuo* so that the magnesium and magnesium chloride are removed by a combination of liquation and volatilization.

The temperature at which this operation is carried out is allowed to rise to about 880°C. At temperatures above 900°C. the zirconium tends to alloy with the steel vessel. A high pumping capacity is necessary to keep the pressure low during the process and the pressure in the vessel steadies to less than 1 micron in the later stages of the process, which lasts for several hours. The purified sponge is allowed to oxidize slightly to reduce its pyrophoricity before being removed from the crucible.

Sodium has been used to reduce zirconium tetrachloride but, although there is information on this reduction from a theoretical and laboratory-scale point of view, very little information on a production scale is available. If the economics of the process are analogous to the sodium reduction of titanium tetrachloride then sodium-reduced zirconium should be appreciably cheaper than the magnesium-reduced metal.

The Van Arkel or iodide dissociation method is applicable to zirconium production. The principle of the method has been described when dealing with both uranium and thorium. It was used mainly for refining zirconium sponge, but improvement in sponge quality has made the iodide process uneconomical. Zirconium tetraiodide, formed as a vapour at 285°C., is decomposed on a hot filament between 1,000°C. and 1,350°C. to yield crystal zirconium. The resulting crystal bar diameter is up to about 1 in. Major reductions in the impurity levels of nickel, chromium and nitrogen and appreciable lowering of carbon, silica, iron, and aluminium occur, together with some reduction of other elements.

The iodide process only becomes worth while if a cheap feed material can be used as the source of zirconium, and work has been carried out to find suitable zirconium sources. The process is not competitive at present for tonnage production.

Another method of zirconium extraction which has been actively pursued in Belgium is the calcium reduction of zirconium tetrafluoride. This reaction is strongly exothermic and yields the zirconium in the molten state so that the metal can be removed in ingot form which is an advantage over the Kroll process. There is difficulty, however, in physically containing the molten zirconium as it is released by the reaction.

Various methods of extracting zirconium by electrodeposition from aqueous solutions and fused salts have been investigated. The major problem is to produce the metal in a coarse state which is not readily attacked by air or water when it is taken from the cell. Russian workers claim to have produced coarse, hafnium-free, pure zirconium by electrolysing potassium zirconium fluoride at 750/800°C.

Melting methods

Sponge zirconium must be consolidated by melting before satisfactory fabrication can be carried out. Since the metal is very reactive there is difficulty in finding satisfactory crucible materials and it is also necessary to use either an inert atmosphere or vacuum to protect the melt. Many crucible materials have been tried for melting zirconium, but only graphite or water-cooled copper have been used extensively. Use of graphite results in a carbon pick-up in zirconium of 0·08–0·3%, which is undesirable for applications where high purity zirconium is required. In particular, the carbon reduces corrosion resistance. For commercial quality zirconium, graphite crucibles are reasonably satisfactory. The graphite crucible is applicable to resistance or induction melting of zirconium and the water-cooled copper crucible is used in arc-melting of zirconium (fig. 26).

Resistance heating involves the use of a split

tube graphite resistor, working in vacuum, with power capacity sufficient to degas the graphite crucible placed in the split tube at 2,000°C. The metal is introduced to the crucible after degassing without breaking the vacuum and heated to 1,000°C. so that the charge is degassed. The temperature is then raised above the melting point of zirconium (1,852°C.), but superheat is minimized to limit carbon pick-up. The crucible may be bottom poured to give an ingot without breaking the vacuum, but the weight of ingot produced by this method has been less than 50 lb.

In high-frequency induction melting of zirconium, both bottom-pouring and top-pouring methods have been used. Again there is a limit on the weight of metal which can be cast, and carbon contamination is inevitable.

Consumable arc-melting of zirconium offers many advantages and is the most extensively used method at present. An inert atmosphere or vacuum is necessary, the latter giving the better product. Zirconium sponge is compacted into bricks measuring about 8 by 2 by 2 in. The bricks are then Argonarc welded together to form an electrode which is assembled in the furnace and connected to the negative side of a d.c. supply. The water-cooled copper crucible base is made positive and currents of 10,000–25,000 amps. are used to continuously melt the electrode to form an ingot in the crucible of 10–20 in. dia. The ingot is normally used as an electrode for remelting into a larger diameter crucible. This double melting technique gives a more homogeneous ingot than is achieved in the first melt, particularly if alloying elements are added.

When alloying is required, the elements are added in powder or granular form in the correct proportions to each brick of zirconium compacted. Care must be taken to avoid segregation and volatilization of low melting point elements such as tin in the first melt. During the melting it is possible to rotate the molten pool, and to some extent the arc, by producing a magnetic field in the crucible by means of coils placed outside. This has the effect of stabilizing the arc and further promoting homogeneity.

It is difficult to stabilize the arc in a vacuum, but stabilization is assisted by high current densities, low furnace atmospheric pressure, short electrode to melt distances and a reasonable clearance between the side of the electrode and the crucible wall.

The consumable electrode method allows melting rates of up to about $\frac{1}{2}$ ton/h. with a power consumption of about 0·3 kWh./lb. and can yield ingots up to 3 tons.

The high cost of melting zirconium and its alloys is associated with the difficulty of remelting scrap which is very difficult to incorporate in the consumable electrode furnace.

Fabrication

The most important precaution to be taken in working zirconium is to avoid contamination, particularly from the atmosphere. Heating zirconium in air results in oxygen and nitrogen surface contamination which is capable of diffusing into the metal. This is more damaging with thin material than with large ingots, but the general effect is to decrease the ductility of the metal and impair its corrosion resistance.

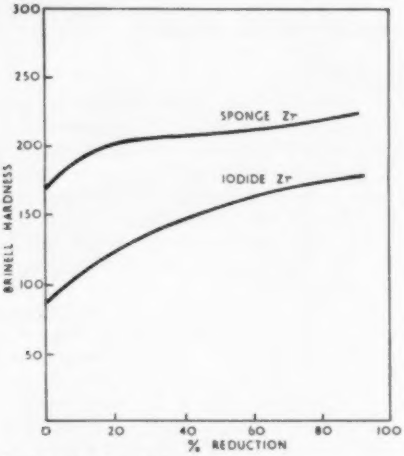
Heavy sections and ingots may be preheated in electric furnaces without a great risk of contamination, but gas- and oil-fired furnaces are not satisfactory unless complete exclusion of the products of combustion from the neighbourhood of the zirconium can be guaranteed. In any case the time and temperature of preheating should be held to the necessary minimum. The preheat temperature for zirconium is 800–900°C. and a slightly higher range for alloys.

Breaking down of ingots may be done by either hammer or press forging. Zirconium is not unduly difficult to work but reductions should be light until the as-cast structure is broken down. Thereafter, heavier reductions may be made and forging continued down to a temperature of about 500°C. Unnecessarily frequent reheating of billets is avoided in order to limit contamination, but several reheats will be necessary to reduce large ingots to slabs.

The starting material for sheet or strip may be slabs up to 5 in. thick. These are conditioned by grinding, shot blasting and pickling in nitric/hydrofluoric acid mixtures to remove scale and defects. After preheating for about an hour at 800–950°C. the slabs are hot-rolled on powerful but conventional mills with heavy reductions to reduce quickly to size without the necessity of reheating. Reheating at this stage would be an embarrassment because of the relatively large surface area to volume ratio which would contribute to contamination.

After hot-rolling, zirconium may be annealed at about 800°C. to develop an equiaxed grain structure, in which case it may be necessary to apply some form of atmospheric protection. The hot-rolled product will in any case be descaled by grit blasting and pickling before further processing.

Hot working of zirconium by extrusion is possible. In addition to the atmospheric contamination problem there is the further problem of galling in the extrusion die. Both problems are overcome by extruding sheathed zirconium, where the billet is surrounded by a container of copper (up to 800°C.), brass, or steel (up to 900°C.) so that only the



27 *Work hardening of zirconium*

sheathing material contacts the die. Precautions are taken to ensure that no turbulent flow of metal occurs which might fold the sheathing material into the zirconium. After extrusion, the sheathing is removed mechanically or by pickling in nitric acid. Zirconium may be extruded without sheathing by preheating in salt baths. The surface of the metal oxidizes slightly and the salt clinging to the billet when it is withdrawn from the salt bath limits further oxidation and also acts as a lubricant in extrusion. A salt mixture of 75% $BaCl_2$ + 25% NaCl is an example for this purpose. Another method of extruding unsheathed zirconium is the Ugine Sejournet process. In this process friction and galling are much reduced by the use of glass applied as wool or fibre matting and acting as a viscous lubricant at extrusion temperatures.

Cold working of zirconium offers no insuperable problem and conventional plant may be used, although the metal work hardens quickly (see fig. 27). With thick sheet an interstage anneal may be required after 30–40% total reduction, but on thinner sheet the total reductions between anneals may rise to 90%. Recrystallization temperatures naturally vary with the purity of the zirconium and the severity of cold working but will generally be in the range 475–575°C. In practice, annealing temperatures of about 625°C. for zirconium and 725°C. for Zircaloys are used. The main difficulty is in avoiding contamination. Relatively thick sections can be annealed openly in electric furnaces, but protection is required for thin sections.

Rod, wire and tube drawing of zirconium are not difficult but it is necessary to have good lubrication to avoid galling. Lubricants include molybdenum disulphide with possibly graphite, chlorinated oil and soap compounds and the use of copper plating and phosphating the zirconium. Drawing dies are generally of the carbide type. Cold-drawn tube is the normal product prior to forming reactor fuel cans.

Galling is the limiting factor in deep drawing, but here again a superficial oxide film on the zirconium carrying a stiff lubricant overcomes the problem in most cases.

During machining of zirconium the swarf produced may be pyrophoric so it is advisable to avoid producing fine swarf. Skimming cuts should therefore be avoided; generous clearance angles and sharpness of the tools, generally tungsten carbide, help in limiting the temperature rise of the swarf. A generous tool clearance also assists in clearing swarf and chips which, being work hardened, will be harder than the machined surface and will abrade it or produce galling. Oxide scale on zirconium is very abrasive and should be removed by grit blasting prior to machining. Cutting oils and coolants may be used, but their use involves considerable cleaning of swarf prior to scrap recovery. Surface contamination of swarf also occurs during machining, from tools, lubricants and particularly the atmosphere. Atmospheric contamination of swarf has to be eliminated by thorough pickling before the swarf can be used as good return scrap.

Normal gas or arc welding of zirconium is unsatisfactory, due to atmospheric contamination of the weld metal. The inert atmosphere electric arc process is, however, very satisfactory and sound welds may be produced free from contamination. Welding of Zircaloy is more difficult and the welds are freer from cracking if made under vacuum. Solid phase welding of zirconium is possible provided the contact surfaces are clean and fully protected during preheating. Bonding is normally allowed to take place *in vacuo* either by diffusion or after some reduction of section across the weld junction. The temperature range where this process is satisfactory is 800–1,000°C.

Zirconium may be brazed to itself or to a number of other metals, again using vacuum or inert atmosphere conditions. Silver, copper and some of their alloys are suitable brazing solders, but excess brazing metal is a disadvantage since it tends to wet the zirconium over an unnecessarily wide area.

English Electric and G.E.C. to discuss merger

The boards of the English Electric Co. Ltd. and the General Electric Co. Ltd. have been jointly considering the general position of the British electrical industry. They feel that many activities of their two groups are complementary and have agreed to explore immediately the practicability of a merger of the two groups by means of a holding company.

Effect of carbide stringers on the distortion of die steels during heat treatment

K. SACHS, PH.D., M.SC., A.I.M.

The causes and mechanism of distortion of die steels during heat treatment, the influence of the structure of the steel and in particular the part played by carbide stringers, are studied. The author is Head of Research, Metallurgy Section, G.K.N. Group Research Laboratory, Wolverhampton, and his article will be continued in future issues

continued from last month

FURTHER increases in hardenability produces steels that form martensite even on air cooling. In such air-hardening steels the temperature gradients during cooling are much less serious than in oil quenching and the risk of distortion is greatly reduced. Another way in which alloying additions can influence the dimensional stability of steels is exemplified in the so-called non-distorting die steels, but these deserve a section to themselves.

Non-distorting die steels

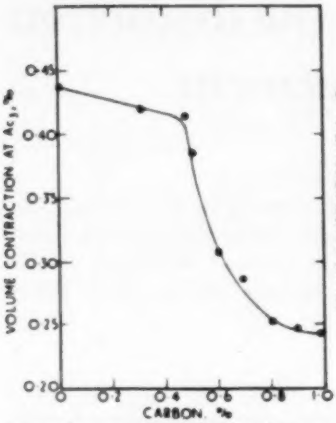
Full hardening and tempering, carried out under favourable conditions, where the temperature gradients are sufficiently mild to avoid local plastic deformation leading to distortion, takes the steel through a sequence of dimensional changes. The steel is machined in the annealed condition and is used after hardening and tempering, when its structure consists largely of tempered martensite. During heating the steel expands up to Ac_1, contracts while it transforms to austenite, and then expands again; in quenching it contracts down to M_s, expands until martensite formation is complete and then contracts a little more. The specific volume of martensite is a little larger than that of ferrite, so that tempering is accompanied by a slight contraction.

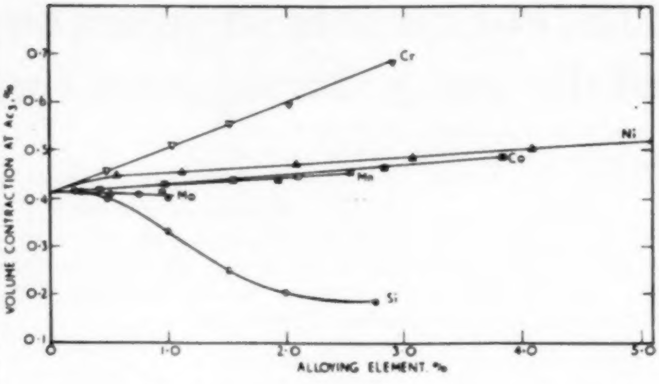
The extent of these volume changes depends on the composition of the steel. The effect of different alloying elements on the contraction at Ac_3, and by inference on the expansion at Ar_3 and at M_s has been studied recently by Kenneford.[8] Experimental steels were produced in a small H.F. furnace and forged to ½-in.-dia. rod. The contraction was measured on the heating curves recorded in a Leitz Universal Dilatometer at a heating rate of 5°C./min.; the specimen was in a rough vacuum to prevent oxidation. The contraction reading was multiplied by 3 to convert it to volume change, on the assumption that the dilatations are isotropic. The results are summarized in Table 1. In order to compare the effects of different elements, a correction had to be made for differences in Ac_3 and the results are converted to correspond to a temperature of 780°C. in figs. 7 and 8. It will be seen that silicon and molybdenum lower the volume changes, and Kenneford developed an alloy steel based on these elements which is remarkably free of distortion and has other valuable properties.[9]

This method of reducing distortion cannot be used in tool and die steels where chromium is an essential alloying element, because chromium considerably increases the volume changes accompanying transformation, as can be seen in fig. 10. Instead, the composition of the steel is adjusted to avoid full transformation to martensite, retaining sufficient austenite to balance the expansion.

In the highly alloyed steels normally used, transformation to martensite is frequently not complete during quenching; the retention of austenite leads to a proportionate lowering of the expansion associated with martensite formation. Austenite may transform on tempering or on cooling after tempering and this superimposes an expansion on the dimensional changes due to the decomposition of martensite into ferrite and carbide. These tempering effects further complicate the overall changes in dimension as well as influencing the hardness of the steel and, in particular, favouring the retention of hardness to relatively high temperatures. The amount of austenite retained in quenching is a function of the composition of the steel, the hardening temperature, and the cooling rate in quenching, and can be used to exercise some control on the overall dimensional changes resulting from heat treatment.

A non-distorting steel is one in which just enough austenite is retained to balance the difference





7 LEFT *Effect of carbon*, and 8 RIGHT, *effect of alloying elements on volume contraction on transformation from α to γ. Corrected to constant temperature to 780°C.* (*A. S. Kenneford*[8])

TABLE 1 *Effect of different alloying elements on volume change of steel at Ac_3. Heating rate 5°C./min.*

Carbon, %	Contraction, %	Temperature of Ac_3, °C.
0·32	0·419	780
0·49	0·443	742
0·51	0·419	733
0·61	0·347	725
0·70	0·329	719
0·81	0·299	713
0·90	0·294	714
0·99	0·289	714

Manganese, %	Contraction, %	Temperature of Ac_3, °C.
0·42	0·419	780
0·95	0·419	775
1·55	0·443	776
2·09	0·459	766
2·54	0·467	762

Chromium, %	Contraction, %	Temperature of Ac_3, °C.
Nil	0·419	780
0·48	0·443	795
1·04	0·503	790
1·51	0·551	788
2·02	0·577	801
2·90	0·653	818

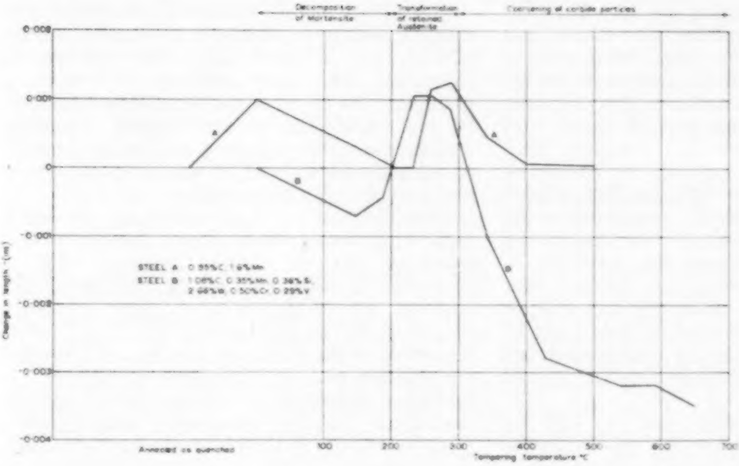
Vanadium, %	Contraction, %	Temperature of Ac_3, °C.
Nil	0·419	780
0·06	0·455	762
0·12	0·443	765
0·20	0·425	775
0·32	0·407	783

Silicon, %	Contraction, %	Temperature of Ac_3, °C.
0·2	0·419	780
0·48	0·359	840
1·0	0·262	887
1·51	0·168	906
1·98	0·090	951
2·76	0·066	957

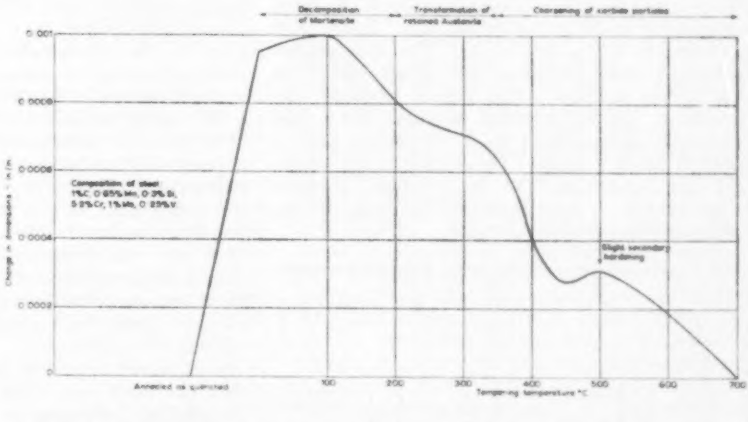
Nickel, %	Contraction, %	Temperature of Ac_3, °C.
Nil	0·419	780
0·56	0·441	792
1·12	0·456	781
2·08	0·479	771
3·07	0·507	744
4·08	0·534	733
5·10	0·557	724

Molybdenum, %	Contraction, %	Temperature of Ac_3, °C.
Nil	0·419	780
0·26	0·427	765
0·49	0·417	767
0·75	0·420	769
1·00	0·408	772

Cobalt, %	Contraction, %	Temperature of Ac_3, °C.
Nil	0·419	780
0·48	0·434	760
0·97	0·442	767
1·92	0·442	776
2·83	0·462	782
3·82	0·480	790



9 *Effect of tempering on dimensions of low-alloy tool steels*



10 *Effect of tempering on dimensions of air-hardening die steel*

between the contraction due to the formation of austenite from a ferrite-pearlite structure on the one hand and the expansion associated with the formation of a mildly tempered martensite on the other. In such a steel the volumes before and after heat treatment should be identical.

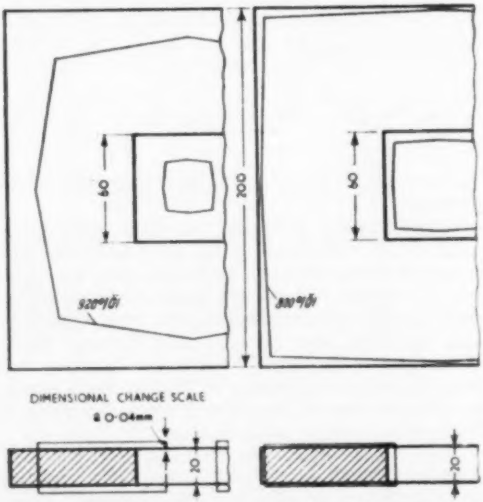
To illustrate the kind of changes that can occur, the length of specimens after tempering at different temperatures has been plotted in fig. 9. The results are taken from the work of Grossman and Bain[1] and refer to tool steels of relatively low alloy content. Unfortunately, the dilatation due to the hardening operation itself is only given for one of the steels. In both steels, break-down of martensite is accompanied by contraction, transformation of austenite by expansion, and coarsening of the tempered structure at higher temperatures by further contraction. Each graph intercepts the dimension of the 'as quenched' specimen at two tempering temperatures

Non-distorting steels of this type, containing about 1% C and relatively low alloy additions, are widely used for intricate tools and dies, for taps, reamers, broaches, bushings, gauges, thread-rolling dies, master tools for shaping form tools, stamping and blanking dies, punches and forming dies.[2] When greater hardenability is required, either because the section is heavier or because the shape is so intricate that air hardening becomes desirable, a higher alloy content must be used.

A typical air-hardening steel used for cold dies contains 1% C, 5% Cr, 1% Mo, with optional small additions of other alloying elements. Scott and Gray[3] studied the distortion of such a steel, cooled in a non-scaling atmosphere from 940°C., and tempered at different temperatures; their

results have been re-plotted in fig. 10. The high chromium content has reduced the dimensional changes on tempering. The compensating effect of the transformation of retained austenite is smaller than in fig. 9. This is a function of the hardening temperature; after hardening from 940°C., the steel with 5% Cr retains about 22% austenite, after quenching from 1,000 or 1,100°C., the amount of retained austenite would be 42% and 85% respectively. Hardening from a higher temperature would increase the degree of control over dimensional changes and might accentuate the possibility of secondary hardening. However, the hardness after air hardening would be lower and any gain in hardness from transformation of retained austenite would require higher tempering temperatures and thus tend to soften the part of the structure derived from the martensite.

This difficulty is overcome, and the wear resistance of the die improved, by increasing chromium and carbon to provide a stiffening of chromium carbide in a matrix of roughly the same composition as the air-hardening steel. Such steels may contain 2½% C and 11–13% Cr; this ensures maximum wear resistance and good control of dimensional stability. The steel is normally oil-hardening, but the addition of about 0·8% Mo renders it air hardening up to the largest section likely to be of interest. The steel is rather brittle and this disadvantage can be overcome, at some slight sacrifice in wear resistance, by dropping the carbon content to about 1·5%.



11 *Dimensional changes of a square plate with a square hole for oil quenching from 920° and 800°C. Dimensions of specimen 200 × 200 × 20 mm.[3], hole 60 × 60 mm.[2]. (J. Frehser and O. Lowitzer[6])*

These steels solidify as austenitic dendrites with eutectic infilling of austenite, chromium carbide (Cr_7C_3), and in some cases chromium-bearing cementite. This cored structure is broken up in forging, and the structure of the forged bar used for the manufacture of dies consists of carbide particles drawn out into long stringers in a matrix of austenite decomposed by annealing into ferrite with very fine globular carbides.

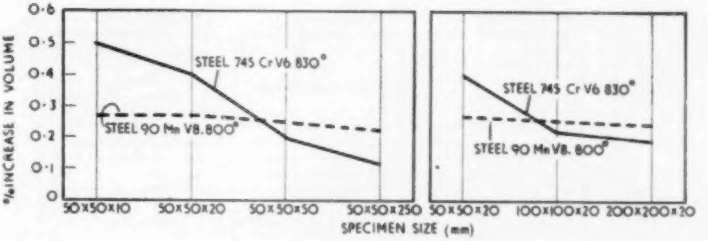
The high-carbon, high-chromium die steels suffer exceptionally small volume changes in heat treatment, but the carbide structure leads to anisotropy of dilatation. In the direction of hot working, hardening causes a slight extension, roughly similar to that found in the 5% Cr steel[3]; movement in the transverse direction is somewhat less and may even be in the opposite direction, *e.g.* transverse contraction.[3, 4] The amount of retained austenite is extremely sensitive to hardening temperature, and this fact can be used to correct dimensional changes. There is very little movement on tempering up to about 425°C., an expansion occurs during tempering at about 450°C., presumably as a result of the decomposition of retained austenite. This temperature is unusually high (fig. 9), owing to the stability of the retained austenite.

The actual amount of austenite retained, which determines the dimensional changes on quenching, depends on the hardening temperature, the time available for carbides to go into solution, and even the temperature of the quenching medium. It is possible to maintain absolutely a selected dimension in at least one direction, by a somewhat elaborate empirical heat-treatment technique.[5] The steel is quenched under conditions favouring retention of austenite, and the contraction on the relevant dimension is measured. It is then tempered at 490°C., when some expansion will occur; if this does not fully compensate for the contraction on quenching, tempering is repeated at a slightly higher temperature until the desired dimension has been recovered. This somewhat laborious procedure may well be justified for expensive tools and dies, but it must be borne in mind that dimensional changes in other directions are not corrected.

Perhaps the last word that need be said about the composition of non-distorting steels is this[3]: the higher the chromium content the less will be the change in volume on hardening, but the greater will be the directional effect.

Relative importance of different factors

In all heat-treated steel, distortion is caused by the combined action of thermal stresses and transformation stresses. In order to compare these effects separately, Frehser and Lowitzer[6] studied low-carbon steels, ferritic and austenitic stainless steels, as well as hardenable tool steels under



12 *Effect of size of component on volume change for two steels of different hardenability (J. Frehser and O. Lowitzer[6])*

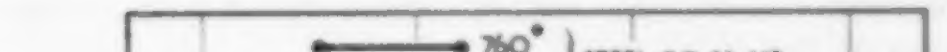
strictly comparable conditions. The stainless steels did not transform during heat treatment, and the mild steel transformed at such a high temperature on cooling that it was still sufficiently plastic for all dimensional changes to be truly reversible; these steels, therefore, distorted under the influence of thermal stresses alone. The hardenable tool steels suffered the combined effects of thermal and transformation stresses, and the influence of transformation alone could be assessed by comparing results on different steels, although crude arithmetical treatment would have to be regarded as an impermissible over-simplification.

Experiments on substantial pieces of mild steel confirmed earlier indications[10] that thermal stresses alone tend to modify the shape of a component in such a way that it approximates more and more closely to a sphere. Spherical specimens did not change their shape at all as a result of thermal stresses on cooling, provided strength, thermal expansion, and thermal conductivity of the material were isotropic. Cubes tended to approach a spherical shape by bellying of the flat faces; bars became shorter and thicker, while plates also grew thicker and shrank in area. These changes in shape are more pronounced the faster the cooling rate. They are also accentuated by more severe temperature gradients, *e.g.* by quenching from higher temperatures.

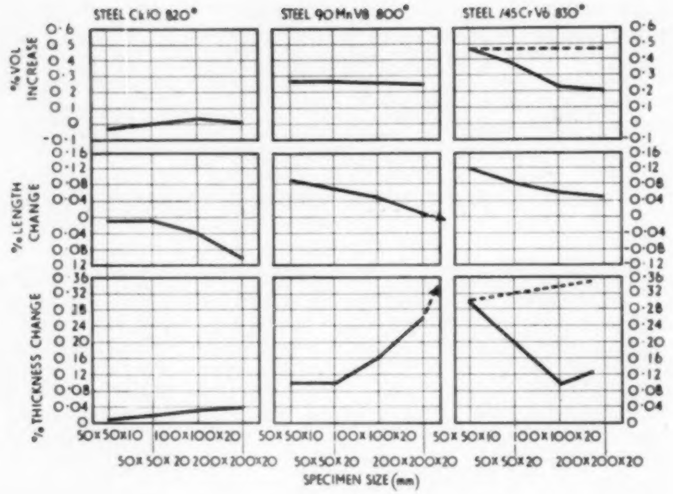
The dimensional changes of a square plate with a square hole in the middle are shown for oil quenching from 920°C. and 800°C. in fig. 11; the higher quenching temperature is associated with a considerable accentuation of dimensional changes. This is due, in part at least, to the fact that thermal distortion can proceed more easily at higher temperatures because the material is softer and more readily deformed by thermal stresses.[11] This interpretation is confirmed by the fact that the non-transforming stainless steels, both ferritic and austenitic, distort much less than the mild steel, because they retain their thermal resistance to deformation at high temperatures much better than does mild steel. Although the distortion is smaller in extent in these steels, it still tends towards the spherical shape.

The experiments on heat-treatable steels confirmed earlier results by other investigators[12, 13] that the degree of distortion was related to the effective hardenability, or the extent to which the component was hardened right through. This is illustrated very clearly in fig. 12 which compares the effect of the size of the component on the volume change for two steels of different hardenability. The more hardenable steel (90 MnV8: 0·9% C, 0·20% Si, 1·90% Mn, 0·15% V) became fully martensitic on quenching even in the larger sizes and the change of volume produced by quenching was virtually unaffected by the dimensions of the specimen. The less hardenable steel (145 CrV6: 1·45% C, 0·20% Si, 0·40% Mn, 1·50% Cr, 0·10% V), on the other hand, shows a considerable drop in volume change with increasing dimensions, as the proportion of fully hardened structure diminished.

A similar graph of volume change against specimen size, for the same two steels, illustrates the effect of hardening temperature (fig. 13). In the less hardenable steel an increase in hardening temperature from 830–870°C. enhances the degree of through-hardening and thus accentuates the volume changes. In the more hardenable steel the increase in hardening temperature from 760–800°C. increases the amount of retained austenite



13 *Effect of hardening temperature on the two steels in fig. 12—90 Mn V8 and 145 Cr V6 (J. Frehser and O. Lowitzer[6])*



14 (*a, b, c*) *Changes in linear dimensions for three steels (J. Frehser and O. Lowitzer*[6])

and thus diminishes the expansion produced by quenching.

The interaction of thermal and transformation stresses is shown in fig. 14, where the effect of specimen size on volume change is broken down into changes of linear dimensions, for mild steel and the two steels of different hardenability. In the mild steel the overall volume change is negligible, but there is a progressive increase in thickness and decrease in the lateral dimensions of the plates. In the steel with higher hardenability (90 MnV8), which is hardened right through in all dimensions considered, a fairly uniform increase in volume is superimposed on these dimensional changes so that the increase in thickness is greatly accentuated; the lateral dimensions also show a slight increase, consistent with the volume expansion, but this diminishes progressively under the influence of thermal distortion which tends to contract the area of the plate.

Extrapolation to even larger sizes, indicated by dotted lines in fig. 14 (*b*), suggests the possibility that the length and width might actually decrease, while the thickness would increase more sharply, to accommodate the increasing volume. However, further increase in size must ultimately lead to failure to harden right through and a corresponding drop in the volume change. The effect of incomplete hardening of the larger sizes is shown in the case of the less hardenable steel, 145 CrV6 (fig. 14 (*c*)). Here the volume change diminishes so sharply that it counteracts the increase in thickness due to thermal stresses.

As the specimens increase in size there is a sharp drop in the thickness increase on quenching, consistent with the drop in expansion. At a certain size (100 × 100 × 20) the increase in volume has dropped to a fairly low figure, indicating that transformation stresses play a relatively small part, and the increase in thickness takes an upward turn under the influence of thermal stresses. It appears that in small components distortion is predominantly due to transformation, but increase in size leads to a progressive increase in thermal stresses and the gradual predominance of thermal distortion with size of component is helped by a decrease in the degree of transformation, particularly in steels of low or moderate hardenability.

The effect of tempering treatments on the dimensions was very complex, depending on the tempering temperature, the amount of residual austenite and its readiness to decompose during or after tempering, the decomposition of martensite during tempering, etc. Superimposed on all this is a slight tendency for thermal stresses to change the shape to a closer approximation to the spherical.

to be continued

B. & S. Massey Ltd., Openshaw, Manchester 11, announces that the following appointments have been made: Mr. J. S. Byam-Grounds as deputy managing director and Mr. J. W. H. Callaghan as deputy sales manager.

Dymet Alloys Ltd., producers of tungsten carbide, have completed their move from Croydon to Camberley, Surrey. The new address is Frimley Road, Camberley (Tel. 4433/4).

The London office of A. P. Newall & Co. Ltd. has moved to 19-20 Grosvenor Street, London, W.1 (Hyde Park 3342).

Creep in steel

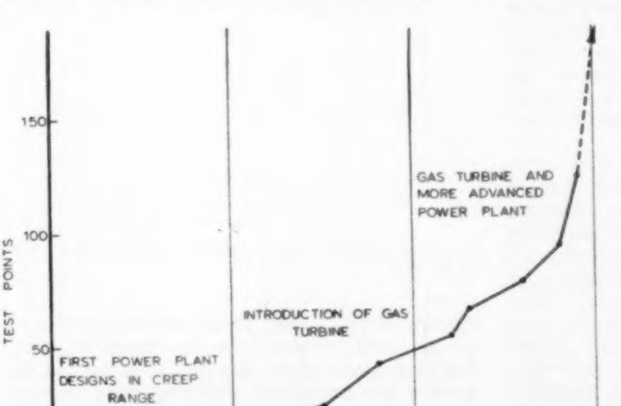
J. D. MURRAY

Introducing his paper, which he presented at the annual meeting of the British Association for the Advancement of Science at Cardiff last September, the author said that little work on the physical or mathematical side of the subject of creep in steel had so far been done. Such treatments that had been made on metals were confined to single crystals and polycrystalline aggregates of pure metals and simple solid solution alloys. The fact that steel was essentially a two-phase alloy of iron and carbon made such a treatment extremely difficult in the present state of the art. Hence, the paper is concerned with the technological aspects of the subject. The author is with the United Steel Companies Ltd. Research and Development Department, Swinden Laboratories, Moorgate

CREEP, which is the deformation that occurs over a period of time under a constant load at and above specific temperatures, was first recognized in and investigated from the early part of this century. With respect to steel the phenomena only becomes of major importance at temperatures above 350°C. and it was not until 1925 that the first creep experiments were carried out on it.

The main interest in the subject arose when power plant design engineers first considered steam temperatures in excess of 350°C. in conventional power stations. From this start there was a steady increase in interest in the subject, and also in the research effort extended on it, up to the outbreak of the second world war. At this stage the development of the gas turbine engine was accelerated and this, in turn, meant that a greater study of creep in steel was required. The post-war years have seen the further development of the gas turbine, renewed interest in conventional power plant and also the development of nuclear power stations.

Fig. 1 gives a good idea of the increase in research effort that has been expended in the past 30 years. It shows the increase in test facilities that has taken place in the laboratory with which the author is connected. The stages that have been mentioned previously are clearly marked. For convenience they have been divided into decades. Possibly the



1 *Increase in creep testing facilities since 1930 in the laboratory of the United Steel Companies Ltd.*

most notable feature is the rapid rate of increase that has taken place in the last two or three years.

It might be inferred from what has been said that this latest increase is due to the development of power plant of more advanced design including those of the nuclear type. There is, however, an additional important factor which has not been mentioned, namely, the change in opinion as to what constitutes realistic information on which to base design. This leads to the consideration of the engineering aspect of the subject.

Engineering aspect

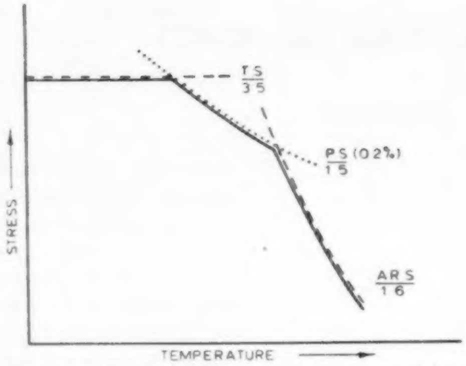
As in all engineering equipment, a component becomes unserviceable when it loses tolerance or, alternatively, when it finally breaks. In connection with the subject of creep, the design of the revolving parts of the gas turbine and similar parts of the steam turbine are generally based on some close tolerance criterion, *i.e.* components become redundant once they have extended beyond a certain limit. On the other hand, in non-moving parts of turbines and in carrier tubing and piping, pressure vessels and boilers, the main criterion of unserviceability is the ultimate rupture of the component.

In general, design engineers are a law unto themselves; consequently, some of their methods for arriving at design stresses are not widely known. However, in plant designed in accordance with National Standard Specifications, certain design codes are evident.

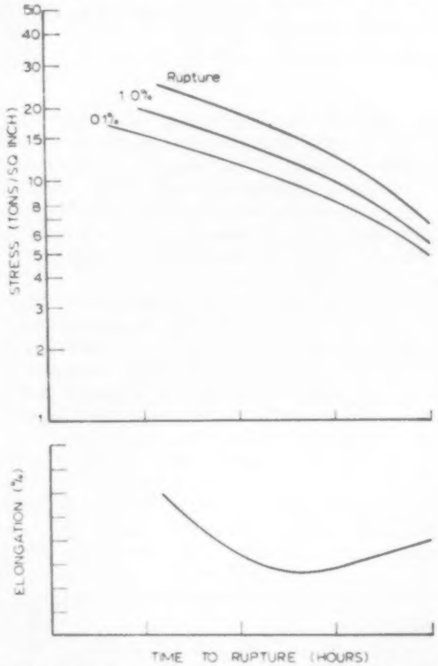
Fig. 2 shows the latest ideas that are being adopted in British Standard Specifications for pressure vessel design. It will be noticed in the plot of stress *v.* temperature that there are three distinct sections to the curve. The first relates to a factor of the tensile strength (TS/3·5), the second to a factor of the proof stress (0·2% proof stress/1·5) and the third to a criterion of creep. In the case shown, 60% of the average stress for rupture has been used as the creep criterion. The design stress is the lowest stress derived from consideration of each of these three criteria.

The above method is very similar to the procedures laid down by the A.S.M.E. Boiler Code in the U.S.A., the values in which are calculated from the following criteria: (*a*) 25% of minimum specified room—temperature tensile strength; (*b*) 25% of the tensile strength at temperature; (*c*) 62½% of yield strength at temperature; (*d*) a conservative average of the stress to give a creep rate of 0·01%/1,000 h. equivalent to 1% plastic strain in 100,000 h.; (*e*) 60% of the average or 80% of the minimum stress to cause rupture in 100,000 h.

It is thus apparent that the engineer makes allowance for the creep that occurs in steel. To do this, he requires to know accurately the creep properties of any given steel over the duration of intended service. More specifically these properties are the stress to cause a specific amount of deformation and/or rupture in a specific time and the ductility at rupture, both properties being required at the temperature of intended service.

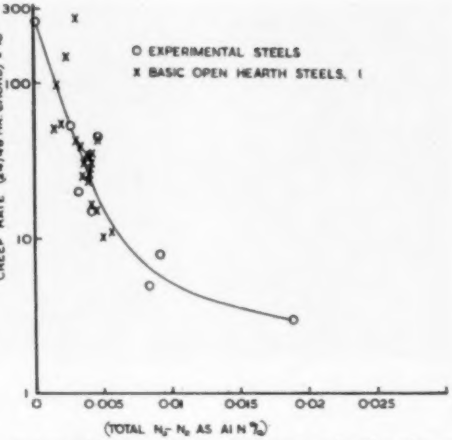


2 *Stress v. temperature relationship for pressure vessel design*

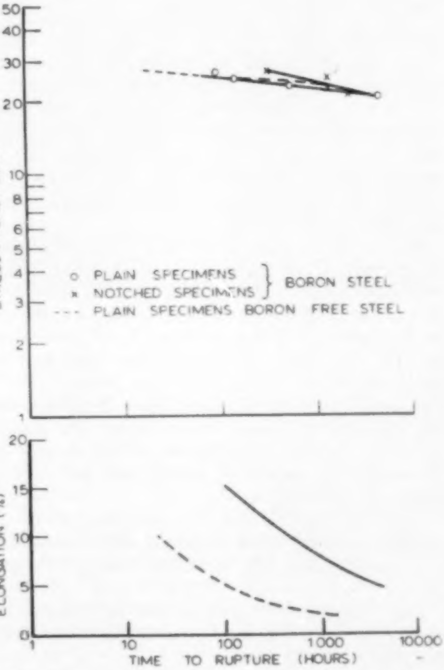


3 *Typical pattern of stress-to-rupture and ductility properties of steel*

Fig. 3 illustrates these properties. It is of importance to note the ductility curve. With increase in testing time the ductility at rupture falls



4 *Relationship between creep resistance and active nitrogen content for carbon steel. Test conditions 8 ton/sq. in. at 450°C.*



5 *Stress-to-rupture data for boron and boron-free steels*

to some minimum value and intercrystalline cracking may be introduced. The minimum value attained depends upon the chemical composition and prior heat treatment. In some alloys the value can be very low and elongation values between 1% and 5% are not uncommon.

An arbitrary value of 5% elongation is widely acknowledged as a desirable minimum value. It is often argued that such a level is unnecessarily high when design is based on, say, the attainment of 0·1% creep strain. The main reason for it, however, is to accommodate localized stress concentrations which are likely to be present in all designs and it can therefore be looked upon as a built-in safety factor.

The determination of these properties is generally left in the hands of the metallurgist, as are the other aspects of the subject which are the development of new alloys and the determination of the general 'know-how' of the materials.

Metallurgical aspects

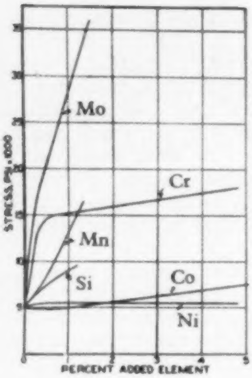
The work of the ferrous metallurgist on the subject of creep falls into three categories:—(1) Fundamental work; (2) development of new alloys; (3) the collection of standard data.

Fundamental works. This is a most important aspect and covers the examination of the effect of chemical composition, steelmaking procedures, heat treatment, and structure on the creep and rupture behaviour. In scientific terms this consists of investigating the effects of interstitial elements (*e.g.* nitrogen and boron), solute atoms, and the allotropic transformation from $\gamma \rightarrow \alpha$ iron

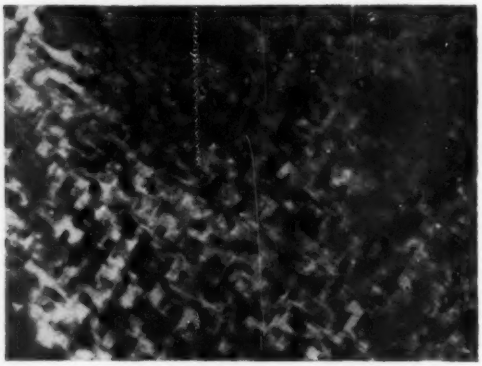
It is important to note that the wide range of strength properties which can be obtained in a steel at room temperature are to a large extent governed by an allotropic change. The temperature at which this allotropic change occurs controls the subsequent microstructure of the steel and, in turn, the change temperature is controlled by chemical composition and heat treatment. By further adjustment to chemical composition and heat treatment hard carbide particles (or intermetallic compounds) can be made to precipitate from the solid solution. Just as reinforcing bars strengthen concrete so carbide particles strengthen steel.

The effect of interstitial elements in steel has in recent years assumed considerable importance. With respect to creep properties the large variation in the properties of aluminium-treated steels has now been shown to be due to the presence of nitrogen and the reaction between nitrogen and aluminium.

Fig. 4 summarizes the work that has been done and shows the relationship between the creep strength and the active nitrogen content. A considerable amount of metallurgical investigation has gone into this topic and it is now clear that the mechanism is one of nitrogen atmospheres, *i.e.* the nitrogen atoms cluster around dislocations



6 *Influence of various alloying elements on the creep resistance of steel*



7 *Evidence of lattice strain in an aluminium 4% copper alloy*

and hinder their movement in a similar manner to that described by Cottrell and Bilby for the yield point phenomena.

Boron also has been shown to have a very marked effect on creep properties and Fig. 5 shows its effect on a low-alloy steel which is commonly used for bolting applications. The main effect to note here is the improvement in the creep ductility that has been brought about by the addition of 0·005% of boron.

The effect is of a transitory nature and, while no metallographic evidence is yet available to explain it, it would appear to be due to the segregation of boron atoms to the grain boundaries. Such a feature would affect the over-ageing tendencies in such regions and therefore the inter-granular cracking behaviour.

Next consider the effect of solute atoms. This can be conveniently sub-divided into the effect on solid solution hardening and the formation of precipitates, *e.g.* carbides, nitrides and intermetallic compounds. Here reference must be made to the classic work of Austin Lindsey and St. John. These workers studied a series of binary alloys in which Mo, Cr, Mn, Si, Ni and Co were alloyed with iron. Fig. 6 shows the solid solution hardening effect of these elements. The authors attributed this effect to increases in the recovery and recrystallization temperatures. It is unlikely that it was a solid solution hardening effect in the true sense since the order of increasing hardness, as measured at room temperature, was different from that appertaining to creep strength.

Considering now the question of alloy carbides, a most important aspect of this subject, a glance at the composition of creep-resisting steels serves to show that all such steels contain elements which have a high affinity for carbon. It is quite obvious, therefore, that alloy carbides and other precipitated phases are extremely important. It has been stated that such carbides should (*a*) be initially coherent, (*b*) have a high resistance to deterioration over-ageing, (*c*) form in even dispersion with fine particle size, and (*d*) that more than one carbide is better than a single carbide.

The formation of a precipitate can be considered as a three-stage process. Firstly, there is the clustering of atoms around a favourable site, then the ordering of these atoms into coherency with the matrix and, finally, the formation of a foreign particle which is initially coherent. This process introduces a considerable internal strain into the matrix lattice and this strain effect will persist until the precipitates lose coherency and agglomerate to form larger particles.

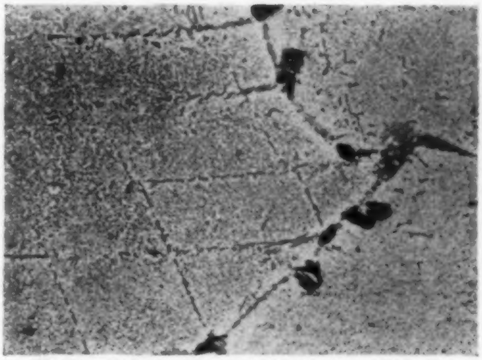
Fig. 7 shows evidence of this lattice strain in an aluminium 4% copper alloy. This effect has not yet been found in steel. This electron micrograph was obtained from the examination of a thin foil of this alloy in a high-resolution electron microscope. The points to note are the light and dark areas where the initial stages of precipitation are occurring. Nutting has stated that these dark areas are undoubtedly strain fields. Once the particles are well formed a dispersion effect occurs and obviously the more numerous the particles the more effective they are.

Figs. 8, 9 and 10 show the precipitation of alloy carbides in creep-resisting steels and in most cases this precipitation has occurred during the creep process.

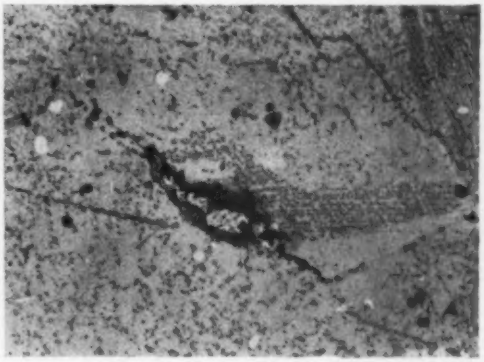
Fig. 8 shows how precipitates have formed on dislocation lines that have generated from boundary defects.

Fig. 9 shows precipitation on piled-up dislocations and the commencement of an intercrystalline fracture.

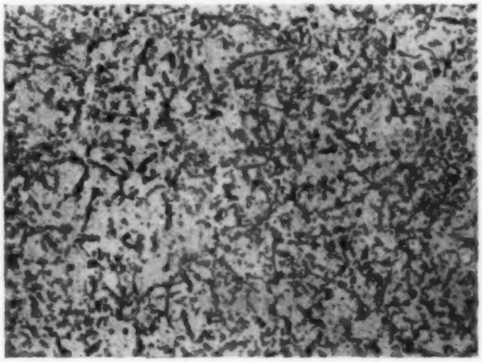
Fig. 10 shows general precipitation on dislocation arrays and Fig. 11 indicates how the difference in coefficient of expansion between matrix and large



8 *Precipitation of alloy carbides at dislocation lines that have generated from boundary defects*



9 *Precipitation of alloy carbides on piled-up dislocations. Commencement of an intercrystalline fracture is also evident*



10 *General precipitation on dislocation arrays*

11 *Indication of the generation of dislocations caused by difference in coefficients of expansion of matrix and large carbide particle. Further precipitation of carbides at these dislocations can occur to give a strengthening effect to the steel*

carbide particle can generate dislocations into which further carbides can precipitate thus giving a strengthening effect to the steel.

Finally, with regard to the effect of the allotropic transformation on the creep behaviour of steel, there is, in the published literature, evidence to show that the different structures obtained vary in order of merit depending upon the test temperature at which they are examined. It has been suggested that strain introduced into the lattice by suppressed transformation appears to be a contributory factor to improved creep resistance. There must be other factors, since different structures of the same hardness give creep strengths.

Stability of structure is obviously important and it would be logical to assume that the most stable structures for a given test temperature would be those formed at or above that test temperature. While it is established that high-temperature strength is affected by differing transformation structures, there is also much evidence that indicates that such effects are of a transitory nature. This is to be expected, since given sufficient thermal activation all non-equilibrium structures will strive to attain equilibrium.

Possibly the most important aspect of the allotropic transformation is in those steels which exhibit strong carbide-forming tendencies, in particular those steels containing vanadium. It has been shown by detailed metallurgical examination that the intensity of the precipitation of alloy carbides is related in part to the temperature of the allotropic change.

Development of new alloys. Since the end of the war the main need for new creep-resisting steels has arisen from the rapid development of the

gas-turbine engine. More recently the fact that temperatures in conventional power plant have exceeded the limit for low-alloy steels has stepped up this need. Fortunately, the lessons learnt from one development can be applied to the other. However, the very different operating conditions of the two plants does mean that in general different types of alloy are required.

Steels for the gas turbine must be capable of carrying very high stresses for short-time periods, whereas those for the steam turbine must withstand much lower stresses for very long-time periods. With respect to gas-turbine alloys and confining our considerations to those alloys of more than 50% iron there are now alloys that will carry three times the stress or operate at 150–200°C. higher than alloys that were available at the end of the war. Similar strides have been made in those steels primarily intended for power-plant use.

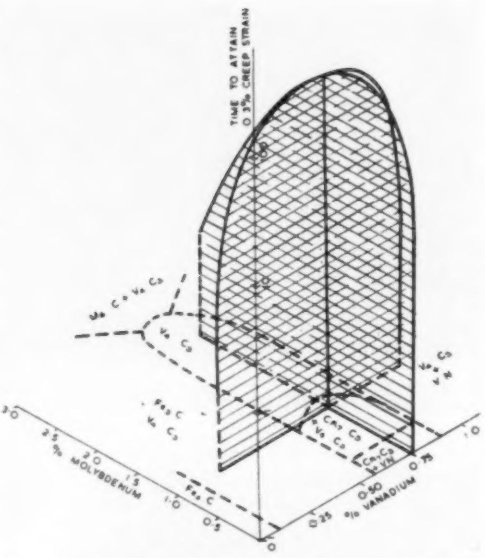
Obviously in the development of new alloys metallurgists must have available the results of fundamental work of the type outlined above. With this information at his disposal he must adjust his chemical composition to give the combined level of strength and ductility that is required.

At the same time it should also be realized that, while he might be developing a steel to resist creep deformation, it is also likely that the steel must be readily weldable, easy to fabricate by bending and drawing and to be capable of meeting some definite tensile-strength requirements. In other words, he is seeking a compromise and the evaluation of the chemical composition is possibly only half of the job. While the correct composition is extremely important, it is also possible that slight changes to manufacturing technique can make better use of the alloy content than if pre-existing procedures were adhered to.

Fig. 12 illustrates the manner in which the chemical composition for creep-strength requirements can be obtained. It is in the form of an isometric plot in which molybdenum and vanadium are shown as a function of the time to reach some creep criterion.

At the base of the diagram are shown the types of alloy carbide that form and it will be noted that the strongest alloy contains 1% Mo and 0·75% V. This alloy is just inside the phase field for chromium carbide and vanadium carbide. This alloy also contains 0·2% carbon and 1% chromium. The carbon content was fixed so as to develop the correct tensile strength and the chromium content was selected to promote better ductility and reduce the risk of graphitization. Having obtained this composition, a great deal of research effort was expended in producing the steel in an economical manner.

Initially in production a prohibitive percentage

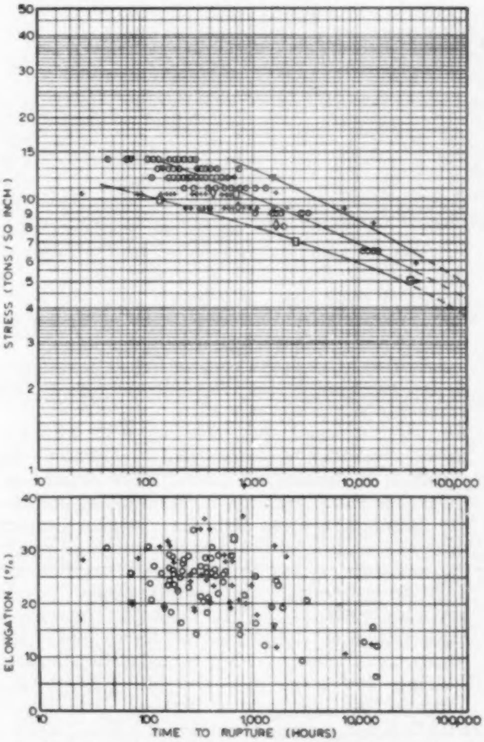


12 *Isometric plot showing the Mo and V contents of steel as a function of the time to attain 0·3% creep strain. The lettering at the base denotes the alloy carbides that form*

of bars produced were rejected due to surface defects. It was only after many months of experiment that the correct heating, hot working, and cooling cycles were evolved which sufficiently reduced the high rejection rate to make the alloy an economical proposition. In building a house it is said that the task is 50% complete when the roof has been put on. Similarly with a new alloy, its development is 50% complete once a composition has been evaluated from laboratory experiments.

The collection of standard data. Under the section relating to engineering aspects it was mentioned that the design engineer must know the properties of a given steel in some detail. Where steels are to be used at room temperature the creep phenomenon does not apply and it is relatively easy to determine typical strength properties. All that is required is to test a sufficient number of different heats to give a statistically significant result.

At temperatures at which creep occurs it must be remembered that the properties depend upon the time period considered. If the properties are required for, say, power-plant equipment where the service life is considered to be in excess of 100,000 h., the problem is difficult. Firstly, 100,000 h. translated to service performance means upwards of 15 years. For continuous running it is approximately 11 years and obviously the determination



13 *Typical test data required on a steel for long-term applications. In this case the steel was CrMo and the test temperature* 1,050°*C.*

and the extension of tests to such times is from many points of view prohibitive.

Up to the last 10 years and, in some instances, today, some design engineers were content to determine the long-term properties on the basis of tests of only 1,000 h. duration. With more knowledge of the subject this procedure is now dying out and, with respect to this country, in the past year a British Standard has been evaluated which lays down the procedures that may be adopted. These are as follows:—

(*a*) When a steel made by more than one steelmaker is to be tested, samples from a minimum of three separate casts from each steelmaker shall be taken. At each temperature of testing, test-pieces from each cast shall be tested at constant loads to cause rupture in approximately 300, 1,000 and 3,000 h. At each of the test temperatures, test-pieces from at least two of these casts from each steelmaker shall be ruptured in 10,000 and 30,000 h. approximately, and one test-piece per steelmaker from one of the above two cases shall be ruptured between 50,000 and 100,000 h.

(*b*) When a steel made by only one steelmaker is to be tested, the minimum number of casts shall be six. At each test temperature, test-pieces from each cast shall be tested at constant loads to cause rupture in 300, 1,000, and 3,000 h. At each of the test temperatures, test-pieces from four of these casts shall be ruptured in approximately 10,000 and 30,000 h., and test-pieces from two of the casts of the four mentioned above shall be ruptured between 50,000 and 100,000 h.

(*c*) In general, at least three test temperatures shall be chosen covering the temperature range within which the rupture properties are likely to be the main basis of design. The temperature of testing shall be a multiple of 25°C. or 50°C., preferably the latter. The stresses shall be reported in ton/sq. in. and shall preferably be a whole number.

Fig. 13 shows typical data required on a steel that is to be used in long-term applications. This data was not obtained on the basis outlined above, but is a collection of all the data that happened to be available in this country. The considerable efforts that must be expended in determining realistic properties will be appreciated from Fig. 13. It will now be readily understood why modern creep laboratories are expanding at the high rate indicated in the first figure.

New technique for measuring the hydrogen content of steels

A large number of common gases are soluble in solid metals, even at ordinary room temperature. Such gases can have far-reaching effects on the way in which the metals behave when subjected to forging and welding, and because of the importance of these processes there is a growing interest in possible ways of measuring the amount of gas dissolved.

The British Welding Research Association has recently described a new rapid technique for measuring the quantity of hydrogen dissolved in steels.

Hitherto the determination of hydrogen in steel has generally been made by heating the sample to about 600–700°C. under a high vacuum, when the gas is drawn out in much the same way as dehydration of materials can be effected by a combination of heat and vacuum. The vacuum system required for this method, however, is expensive and fragile and the analysis takes quite a long time.

In the new BWRA technique, argon is passed over the sample of steel which is heated in a furnace. The gas evolved is swept along to a hydrogen-sensitive cell from which the result is plotted directly on to an electrical graph recorder in the form of a peak. The system is so accurate that as little as 1 p.p.m. hydrogen can be detected and measured. The analysis time with this apparatus is 15 min. compared with about 2 h. for the more usual instrument. A patent application has been made.

Russian forging journal

Abstracts from the Russian forging journal—Kuznechno-Shtampovochnoe Proizvodstvo, April, 1960, **2.** *This is the second year of this journal devoted specifically to forging. We shall try to give indications of the contents of future numbers in* METAL TREATMENT *each month.*

Determination of the press force and the weight of the dropping components of a hammer, required for hot forging. O. A. GANATO, R. A. VAISBURD and I. YA. TANOVSKII. Pp. 1–7.
The authors derive formulae for the calculations of these parameters, and a comparison of calculated with experimental values shows the validity of the equations obtained. The effect of stamping shape on press force was also studied for a series of typical forging shapes.

The effect of hot working conditions on the properties of heavy components. M. P. BRAUN, B. B. VINOKUV, E. I. MIROVSKII, A. L. GELLER and L. G. MAR'YSHKIN. Pp. 8–11.
Experiments conducted to determine the effect of an increase in the heating temperature on the mechanical properties of steels, their macro- and micro-structures and their plasticity and the possibility of shortening the forging process showed that an increase in the ingot heating temperature of Cr-Ni-Mo, Cr-Ni and Cr steels by 30–40° above the normal does not reduce plasticity during working nor does it worsen the mechanical properties, if the whole process is carried out in one operation and the final forging temperature is not too high. An unavoidable increase in holding time at forging temperature is also not detrimental.

Changes in the structure of cast metal during plastic compression. D. N. BEREZHKOVSKII. Pp. 12–16.
A study was made of such changes during triaxial inhomogeneous compression and of the effect of the temperature, rate and degree of working on their nature in relation to the heat-resisting nickel alloy EI 765. Specimens 30 mm. in dia. and 40 mm. high were cut from the coarse columnar crystal zone so that their axes coincided with ingot radii, heated to 700–900° and compressed by 30% at 900, 1,000, 1,100 and 1,200°C. in a hydraulic press at rates of 5–20 mm./sec. and on a hammer with a rate of stroke of 4·5 m./sec. Then they were immediately quenched in water. Compression in one direction can completely or partially transform the coarse crystalline cast structure into a deformed fine grain structure, for which the final forging temperature must be higher than the recrystallization temperature, and the degree of working not less than a fixed value for the given type of alloys. The recrystallization rate of an EI 765 type alloy from 1,100°C. is fairly high and in certain sections of a specimen may occur during the action of the press or hammer, so that working temperature should be as high as possible (>90% of m.p.) and degree of working 40%. Working on a hammer produces transformation of the structure throughout a greater volume of a deformed body than on a press. The nature of the transformation was also revealed in microstructures of the quenched specimens.

The effect of the holding time at forging temperature on the plasticity of the alloy EI 437. B. M. YA. DZUGUTOV and B. F. VAKHTANOV. Pp. 17–19.
For such a typical heat-resisting steel with low plastic properties it is important to determine the optimum or maximum heating rates which will ensure the absence of internal hot cracking and also the optimum holding time for complete heating through. During heating, conditions should permit the sequence within the required limits of the diffusion processes, *e.g.* homogenization of the structure, reduction of the dendritic segregation, more complete dissolution of the excess components, and grain growth in already worked metal. Holding for 2 h. at 900–1,200° considerably improves the plasticity of the cast structure of EI 437 B, and prolonged holding at 1,050–1,200°C., accompanied by grain growth of a deformed structure, does not in practice reduce the plasticity of this alloy.

The basis of the method of determining the condition of reduction during ring forging. I. M. BALYASNYI. Pp. 19–23.
Ring forging on a mandrel under a press or hammer is here studied in relation to the kinematic system and the stress conditions of the movement of the billet by the action of the rotating mandrel. A simplified method of solving this problem is set out subject to the condition that elongation during the deformation process does not influence the position of the centre of gravity of the billet. An examination is made of the zone of deformation and the system of stresses applied to the billet during the rotation of the mandrel after reduction, and at the intermediate point of the first stage of movement, of the limiting conditions of the first stage of movement, the position of the billet at any point of the second stage of movement and finally at the end of the second stage. Apart from the determination of the value of the angle of rotation of the mandrel, it is also necessary to determine the mutual displacement of the centre of gravity and geometrical centre of the billet asso-

ciated with the differing weights of the worked and unworked parts of the billet in a given turn, which governs the flow of the metal along the width of the ring in the zone of deformation, and the initial position of the billet on the mandrel before alternate reduction or more accurately the value of the delivery of the billet in a given turn. Comparison of calculated and experimental data showed the validity of the theoretical conclusions and their practical application for the calculation of rational working conditions.

Precision and flashless forging abroad. I. F. GOLOVNEV. Pp. 23–25.
New developments in Czechoslovakia and the Western World.

Calculation of the columns of crank presses. P. G. ORLOV and L. V. KOROBIN. Pp. 26–30.
Calculation methods for the design of these columns are outlined in detail.

An automatic regulator of the level of a U 050 vacuum accumulator plant. V. A. KRESIN, G. A. SOKOLOVSKII and B. M. USTENKO. Pp. 30–32.
A regulator based on induction load cells is described in detail.

A new forging manipulator. P. D. NEPECHII and S. A. VOL'SKII. Pp. 32–36.
A full description is given.

Technical and economic indices for automated rapid cold strip stamping. F. I. MIKHALENKO and G. V. KLIMOV. Pp. 36–39.
Calculation shows that the outlay on the automation of cold stamping production processes and the introduction of automated high-speed cold stamping on a mass-production basis are rapidly amortised.

A loading device for automatic forging lines. B. A. CHELISHCHEV. Pp. 40–41.

A device for automatic delivery of sheet and strip to stamping presses. G. V. LEIZERIN. Pp. 41–42.

A universal blanking press for rectangular billets. V. M. KOLOSOV. Pp. 42–43.

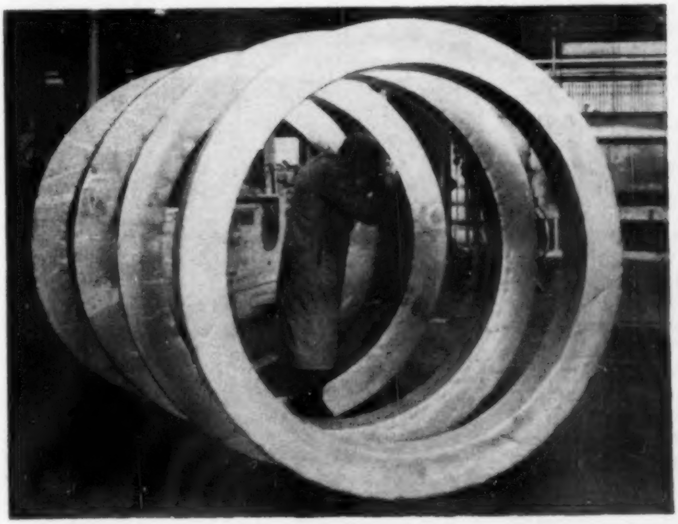
The use of cup-shaped springs in the stamps of blanking presses. S. V. LYASHCHENKO. Pp. 44–48.

Automation in the iron and steel industry
MR. W. M. LARKE (Stewarts & Lloyds Ltd.) was chairman of the first conference on automation in the iron and steel industry, organized by BISRA and held at the Palace Hotel, Buxton, last month. The opening address was delivered by Lord Halsbury, President of the Operational Research Society and one of the pioneers of computer technology in this country.

Lord Halsbury emphasized that the first step toward automation in any industry was the collection of operating data by means of full plant instrumentation. Only after complete operating data was available could the necessary operating rules be calculated for use with 'on line' computers in the automatic control of processes.

Mr. S. S. Carlisle, an assistant director of BISRA with responsibility for automation matters, followed the opening address with an introductory review of automation in the industry. In this he discussed some sections of steelworks practice where the technology was already available to apply more automation. Examples were hot and cold strip mills, primary and plate mills, and forging presses. There was, moreover, virtually complete instrumentation of the blast furnace and open hearth furnace.

Change of telephone number
High Duty Alloys Ltd. announces that the telephone numbers for its Forging Division are now: Redditch 4211 (Day); Redditch 4162 (Night).



Forged aluminium rings for nuclear reactors
Work has recently been completed on the forging of four aluminium alloy rings which will eventually form part of nuclear reactors. These are believed to be the largest forged aluminium rings ever produced in this country, each unmachined ring weighing approx. 1,300 lb., with o.d. 76 in., i.d. 61¾ in. and thickness 8¼in. The rings were forged for the APV Co. Ltd. in Noral 54S aluminium alloy at the Handsworth, Birmingham, works of Alcan Industries Ltd.

Each ring was formed from a cast rectangular-shaped blank which was pierced to receive a mandrel and was then subjected to several ringing and flattening operations, using progressively larger mandrels until the finished forging of over 6 ft. o.d. was obtained. The ringing operations were performed on a 1,200-ton hydraulic press and the flattening operations on a 4,000-ton hydraulic press.

Aluminium production at Rogerstone

ALCAN INDUSTRIES LTD., formerly Northern Aluminium Co. Ltd., is expanding its production facilities in a four-year programme which is expected to cost some £10,000,000. The intention is to increase output to meet the growing needs of established markets and also to provide the means of efficient production of commodities for which a demand has more recently emerged.

The scheme concentrates on improvements to the existing continuous strip mill which was laid down at the company's Rogerstone works in 1949 and 1950, when provision was made for an increase in output and range of product by subsequent development. It covers the installation of new equipment, the modernization of some existing equipment to increase operating speed and versatility, and at several points the relocation of plant to improve the flow in the mill. When the work is completed the nominal output of sheet and strip will be raised from 50,000 tons a year to 70,000 tons a year, plus a substantial extra capacity for hot-rolled coil and plate. A greater proportion of the output will be of material made from the stronger alloys, and also of aluminium alloy plate, which will be available in substantially greater widths than hitherto.

The plate, to a maximum width of well over 10 ft., will be rolled by the new 144-in. hot mill, which is the biggest item of new equipment being installed. This completes the facilities for the production of wide plate at Rogerstone, complementing a large stretcher, a plate saw and an ultrasonic inspection bath which have been operating since 1958.

Outline of the development

A new Remelt Department, with facilities for casting ingots up to a maximum of about 8 tons, if required, will be in production in 1961, but the local casting capacity will still, for convenience, be augmented by importing rolling ingots in certain alloys from Canada.

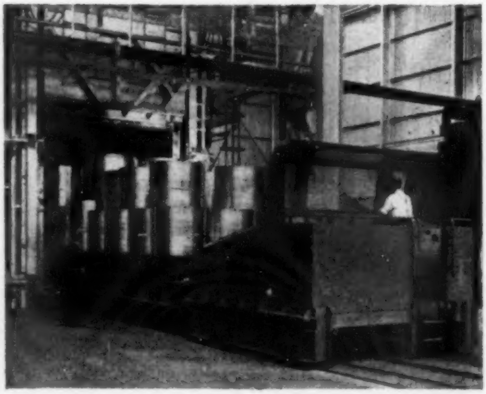
A separate Swarf Remelt Department is used to recover swarf and certain types of scrap. It was originally equipped with four induction furnaces and was situated on the site required for the new mill. The relocated Swarf Remelt Department is equipped with only two of the original furnaces, which have been uprated and enlarged to process the increased quantity of swarf and scrap associated with the increased output. The casting unit served by the furnaces has been improved to permit the casting of larger ingots. In rehousing this department much attention has been paid to working conditions, particularly with respect to fume extraction, and two new systems are fitted over the furnaces and dross pit. The fumes extracted by both systems are cleaned before being discharged.

After remelting and casting the ingots have to be scalped and the existing scalping facilities are being modified to deal with the increase in production under the present scheme.

After scalping, the ingots are pre-heated prior to hot rolling. The four tunnel-type pre-heat furnaces supplying the existing hot line were unable to deal with the increased size of ingot and volume of production. The required additional capacity has been provided by augmenting the present furnaces by a new bay having four furnaces, which is designed as the first stage of a pre-heat department capable of supplying the needs of the continuous strip mill to its ultimate development. The new furnaces are of the pit type, set at floor level, which have greater flexibility of operation, needed when rolling a variety of alloys, than tunnel furnaces. The pits are oil-fired for economy, but are designed to protect the ingots from harmful products of combustion by the use of an indirect heating system, in which the burners heat banks of radiant tubes over which the circulating air is passed.

Hot rolling

In hot rolling, the first of the rolling stages, the pre-heated ingot is passed through a series of mills, emerging from the last as strip. The original layout of the hot line consisted of a 96-in., 2-high breaking-down mill, followed by an 84-in., 2-high breaking-



One of the new oil-fired annealing furnaces being charged with a tray of coils

down mill and, finally, by a 2-stand, 88-in., 4-high hot-finishing mill. The strip, when it emerged from the 88-in. mill, was conveyed on a roller table some 650 ft. long to an upcoiler.

To meet increased output it was decided to install at the beginning of the line a 144-in., 4-high mill, which could be used for breaking-down to feed the hot line or, alternatively, for the production of plate up to 138 in. wide. The 96-in. mill remains, but the 84-in. mill will be dismantled. A third stand has been added to the 88-in. mill, and a trimmer and down-coiler installed close up to the last stand of the 88-in. mill.

Between the new 144-in. mill and the point at which the original hot line began other equipment has been fitted to shear and handle the wide plate. A new ingot tilter is fitted to the tables between the shear and the 144-in. mill to load ingots from the tunnel furnaces for rolling while the plate just rolled is being sheared and lifted from the tables. The feed tables to the new mill collect ingots from the new pre-heat bay. The mill is driven by two 4,000-h.p. single-armature d.c. motors, each linked to one work roll by a forged steel spindle.

The control cabin is set beside the entry tables, affording a good view to the operator, who sits at a low desk and normally controls the mill functions through short lever controls on the desk. Mill operations are recorded by large dials set at low level on the line of sight to the mill. The mill operator usually controls the main mill tables, but control of some can be transferred to the shear operator or to the 96-in. mill operator. The thickness of rolled plate is automatically indicated by a gamma-ray gauge located on the outgoing side of the mill. There are provisions on the mill and within the control cabin for closed-circuit television to show the far side of the mill to the operator.

The whole 144-in. mill bay is served by a 125-ton crane which is used for plate handling, roll changing and other maintenance work. The crane has access to the enclosed motor room through high-level aluminium roller shutters.

The extra rolling capacity gained by the addition of the 144-in. mill and the third stand in the hot-finishing mill has led to alterations in the original layout of the hot line, the main change being the proposed removal of the 84-in. intermediate roughing mill. The existing 96-in. roughing mill will now be required to act as an intermediate mill as well as in its former role. The edge trimmer, previously situated immediately before the hot-finishing stand, will be moved and erected in the position on the line vacated by the 84-in. mill. Placed here it can edge-trim slabs up to 200 ft. long without having to be synchronized with a mill and without holding up the rolling programme. The third stand added to the hot-finishing mill is identical to the two existing stands, being a 4-high non-reversing mill with rolls 88 in. wide.

Cold rolling

Coils taken from the hot line are allowed to cool before being cold-rolled to the finished thickness. Usually, and especially with the harder alloys, one or more reductions in the cold mill are followed by annealing and final treatment in a temper mill.

The annealing furnaces are included in the cold mill bay, and the equipment is completed by an edge trimmer and slitter.

Demands on the original cold-rolling equipment —a 3-stand tandem and a single-stand temper mill—have been eased in part by an increased efficiency due to the larger coils and greater range of gauges from the improved hot line. Capacity will be further increased by installing a modernized 2-stand cold mill, moved from the east works, but this will not be in production until 1961.

This 72-in. tandem in the east works has already been fitted with an improved lubrication system to ensure a high-grade finish at the higher rolling speeds that will be made possible by fitting a 2,200-h.p. motor to each stand. Rolling speeds will be substantially increased from 360 ft./min. to 2,500 ft./min., which is expected to effect a 1,000 ton/month increase in output. Provision is being made so that a further two 2,200-h.p. motors could eventually be fitted, in tandem, to give a total power of 4,400 h.p. per stand, whilst at the same time automatic gauge control will be installed to get the maximum potential output implied by the changes to the main drive. Refinements to the infeed arrangements are also introduced to accept the thicker gauges, in line with the greater versatility of the hot line. This mill will be housed in the recently completed cold bay extension.

Annealing furnaces

The greater amount of harder magnesium-bearing alloys in the increased output of the cold mill has required a more than proportional increase in annealing capacity. To this end existing gas and electric furnaces have been augmented by two new Stein & Atkinson oil-fired coil-annealing furnaces with controlled-atmosphere plants.

The furnace and furnace door construction is a steel shell lined with heat-resisting alloy plates and Stillite insulation. The door is counterbalanced to assist the raising and lowering winch and, when closed, is pressed by hydraulic pushers against a seal of water-cooled sponge strip insert.

Each furnace has a clear load space of 2,230 sq. ft., is 27 ft. long by 10 ft. high by 8 ft. 3 in. wide, and can accept 16 coils of 46-in. outside diameter stacked 70 in. high, weighing a total of 67 tons. Different

coil sizes would allow a possible maximum charge of 112 tons.

Special burners, developed by Stein & Atkinson in conjunction with Surface Combustion Corporation, use marine-diesel oil to heat high-quality stainless steel radiant tubes fitted in the sides of the furnace and insulated from the furnace interior. Air is drawn over banks of these tubes by water-cooled recirculating fans, supplied by Keith Blackman Ltd., and is then ejected at the base of the furnace sides into plenum chambers zones, which may be separately controlled, and which are a part of the annealing tray. The hot air then passes up through the load and is recirculated by the fans. The fans, driven by 40-h.p. motors at 1,480 rev./min., develop 1½-in. water gauge, giving a delivery of 30,000 cu. ft./min. at 600°C.

The furnaces have an operational heating range from 150–600°C. and can hold a selected temperature within that range of ± 3°C. They operate nominally on a 12-h. cycle per load, which gives an annual throughput of between 24,000 and 30,000 tons.

Coils that are to be annealed are stacked, lying either vertically or horizontally, on specially designed trays. The trays are handled by a 50-ton motorized grab and lifted on to a furnace bogie by a 60-ton Morris crane serving the new cold mill bay. The bogies are on rails opposite the furnaces and are charged or discharged by an electrically-driven cab unit.

A Holmes Kemp controlled-atmosphere plant has been installed by Stordy Engineering Ltd. This plant will give a non-oxiding atmosphere which reduces the amount of oil staining at low temperatures. Automatic control is used and has been supplied by Honeywell Controls. The system may be preset to requirements and incorporates all the usual indicators and recording equipment.

Products of the expanded mill

The expansion has been designed not only to make possible an increased volume of the products for which the mill was originally laid down 10 years ago, but also to cater for the demand that has subsequently developed for the stronger alloys and for plate of ¼ in. thick and over.

Building sheet. Aluminium sheet, generally corrugated, is increasingly used for the roofing and siding of industrial buildings. Building sheet is normally made in the 1¼%-manganese alloy Noral 3S, and is often given a 'stucco' finish by rolling between embossed rolls.

Container sheet. The packaging industry uses aluminium sheet for many types of rigid container, such as slip-lid boxes. In this field aluminium is competing with tinplate, and it is therefore supplied in small, standardized sizes for use in existing machinery. Gauge ranges from 0·008–0·018 in. Much container sheet today is in the comparatively hard 2%-magnesium alloy, Noral M57S (BS 1470 : NS4).

Foil stock. Very large quantities of aluminium foil are used in packaging, and there are other substantial outlets in thermal insulation and electric condensers. Alcan Industries supply foil producers with annealed coils of high-purity strip for rolling down.

Circles. Domestic hollow-ware was one of the earliest uses of aluminium and circular blanks of sheet are supplied by Alcan Industries to the manufacturers. Differing directional properties in the sheet or other metallurgical faults can give trouble during forming and special production techniques are employed to avoid them. Circles are usually supplied annealed, but an interesting development by Alcan is the differentially-annealed blank, in which the centre of the blank, which will not be subsequently formed, is hard, whereas the edges are soft to permit working.

General sheet products. The broadening of the range of alloys that the mill can efficiently handle means that sheet for innumerable applications will be produced. Some will be used flat, for example for panelling, but much will be required for further manipulation—pressing, stamping and otherwise forming—and joining by welding, brazing, riveting, etc.

Plate. Rolled material ¼ in. thick or more is defined as plate. It is normally hot-rolled only; it therefore has a duller finish than most sheet and if high strength is required it must be heat treated.

The ability of aluminium plate to withstand rough usage has led to its use for dumper and tipper vehicles handling rock and ores; for railway mineral wagons; and for coal chutes. Its freedom from low-temperature embrittlement makes it the most suitable material for bulk storage of liquefied gases, such as methane, and there are many other applications in the chemical and general engineering industries.

The new 144-in. mill brings a big advance in available plate size: from 6 ft. to well over 10 ft. in width, and up to 50 ft. long. A feature of Noral plate is that it can be supplied with edges sawn straight to very close limits.

A rather specialized product is plate for aircraft construction. This is in high-strength alloys such as Noral B26S (D.T.D. 5040), and usually supplied in a thickness of several inches for machining into a structural component having stiffening members integral with the skin. This plate must have good mechanical properties in all directions, and must be free from residual stresses that would cause distortion during machining.

Welding in Russia

Following a two weeks' visit to welding research institutes in the Soviet Union a party from the British Welding Research Association returned with the impression that emphasis there is placed more on the application of new welding processes, and the associated problems, than on fundamental work for the sake of increasing knowledge. This arises from the all-out drive to expand production and the clear realization of the part played by welding toward that end. The importance of welding in the modern engineering and constructional programmes is probably more deeply appreciated in Russia than in this country

The BWRA party comprised: the director of research, Dr. Richard Weck; the deputy director, Mr. H. F. Tremlett; the assistant director, Dr. A. A. Wells; and the chief metallurgist, Mr. P. T. Houldcroft. Five principal institutes were visited

THE VISIT TOOK PLACE under the auspices of the U.S.S.R. State Scientific and Technical Committee, division for English Speaking Countries, and resulted from negotiations carried on with this Commission by Dr. D. A. Senior, the British Scientific Attaché in Moscow. It was arranged at this time to coincide with the opening of a Welding Exhibition in Moscow within the permanent Exhibition of the Economic Achievements of the National Economy in the U.S.S.R.

The party was impressed by the standard set by this exhibition and by some of the exhibits, particularly in the fields of cold pressure welding (dissimilar metals), friction welding and diffusion welding. Automation and mechanization of welding processes was the dominant theme. Specific items of interest were: a portable flash welder with contour transformer to deal with pipes up to 700 mm. in dia.; an automatic twin-head circumferential CO_2 welding machine for the same size of pipe, and a whole range of tungsten arc welders dealing with pipes in a variety of materials and sizes from 10 mm. dia. to 180 mm.

Mass-produced storage tanks

Methods to overcome the difficulties of distance and transportation to outlying areas were in evidence, and storage tanks up to 50 ft. dia. were shown which were prefabricated and rolled up for transport to site, where the rolls were subsequently pulled open by means of tractors and assembled with the minimum of site welding. Pipelines are dealt with in the same way, being welded in the flat and coiled for despatch. Using a tractor-pneumatic combination, workers expand the 600-m. coils into cylinders on site.

The acceptance standard for finish of welded components is lower than would be the case in this country; puckering on the face of sheet materials when welding on studs, for example, is accepted in the manufacture of car bodies. This, however, is considered of secondary importance to the functional quantities of what is produced.

Of the five research institutes visited, only one was entirely devoted to welding. One of the others was the research laboratory of a factory devoted to the manufacture of arc- and resistance-welding equipment; another was equivalent to a university department, and in two others welding was a department in an institute which had very much wider terms of reference. In only one of the institutes—the Baikov Institute in Moscow—is most of the research fundamental. In the other institutes, although some fundamental work is carried out, most of the research is directed towards the eventual development of new welding processes and new processes of manufacture.

Whilst the research and development effort in the Soviet Union in welding technology is on a very much bigger scale than it is in this country, this is to be expected from the difference in size between the two countries. There are some quite outstanding achievements, but there are also certain spheres where, owing to the special conditions in the Soviet Union, work is not as far advanced as in this country. Welding of aluminium alloys by the inert gas metal arc-welding process appears to be further advanced in this country than in the Soviet Union. On the other hand, the emphasis on submerged arc welding has led to the development of methods and suitable fluxes for the welding of aluminium alloys, titanium alloys and of copper. The joints appear to be of good quality and are claimed to have properties not very inferior to those of the parent material.

The conditions prevailing in many parts of the Soviet Union are unique, and processes may be developed under the pressure of economic factors different from those existing outside that country. Friction welding, for instance, can sometimes serve as an alternative to resistance flash welding and requires less power. The urge to develop this process came from the possibility of its use in areas of very limited power supply. Another illustration based on difficulties of supply is bare wire welding using steam as the shielding gas instead of argon or carbon dioxide.

It was apparent that the usual delay between the

coil sizes would allow a possible maximum charge of 112 tons.

Special burners, developed by Stein & Atkinson in conjunction with Surface Combustion Corporation, use marine-diesel oil to heat high-quality stainless steel radiant tubes fitted in the sides of the furnace and insulated from the furnace interior. Air is drawn over banks of these tubes by water-cooled recirculating fans, supplied by Keith Blackman Ltd., and is then ejected at the base of the furnace sides into plenum chambers zones, which may be separately controlled, and which are a part of the annealing tray. The hot air then passes up through the load and is recirculated by the fans. The fans, driven by 40-h.p. motors at 1,480 rev./min., develop 1½-in. water gauge, giving a delivery of 30,000 cu. ft./min. at 600°C.

The furnaces have an operational heating range from 150–600°C. and can hold a selected temperature within that range of ± 3°C. They operate nominally on a 12-h. cycle per load, which gives an annual throughput of between 24,000 and 30,000 tons.

Coils that are to be annealed are stacked, lying either vertically or horizontally, on specially designed trays. The trays are handled by a 50-ton motorized grab and lifted on to a furnace bogie by a 60-ton Morris crane serving the new cold mill bay. The bogies are on rails opposite the furnaces and are charged or discharged by an electrically-driven cab unit.

A Holmes Kemp controlled-atmosphere plant has been installed by Stordy Engineering Ltd. This plant will give a non-oxiding atmosphere which reduces the amount of oil staining at low temperatures. Automatic control is used and has been supplied by Honeywell Controls. The system may be preset to requirements and incorporates all the usual indicators and recording equipment.

Products of the expanded mill

The expansion has been designed not only to make possible an increased volume of the products for which the mill was originally laid down 10 years ago, but also to cater for the demand that has subsequently developed for the stronger alloys and for plate of ¼ in. thick and over.

Building sheet. Aluminium sheet, generally corrugated, is increasingly used for the roofing and siding of industrial buildings. Building sheet is normally made in the 1¼%-manganese alloy Noral 3S, and is often given a 'stucco' finish by rolling between embossed rolls.

Container sheet. The packaging industry uses aluminium sheet for many types of rigid container, such as slip-lid boxes. In this field aluminium is competing with tinplate, and it is therefore supplied in small, standardized sizes for use in existing machinery. Gauge ranges from 0·008–0·018 in. Much container sheet today is in the comparatively hard 2%-magnesium alloy, Noral M57S (BS 1470 : NS4).

Foil stock. Very large quantities of aluminium foil are used in packaging, and there are other substantial outlets in thermal insulation and electric condensers. Alcan Industries supply foil producers with annealed coils of high-purity strip for rolling down.

Circles. Domestic hollow-ware was one of the earliest uses of aluminium and circular blanks of sheet are supplied by Alcan Industries to the manufacturers. Differing directional properties in the sheet or other metallurgical faults can give trouble during forming and special production techniques are employed to avoid them. Circles are usually supplied annealed, but an interesting development by Alcan is the differentially-annealed blank, in which the centre of the blank, which will not be subsequently formed, is hard, whereas the edges are soft to permit working.

General sheet products. The broadening of the range of alloys that the mill can efficiently handle means that sheet for innumerable applications will be produced. Some will be used flat, for example for panelling, but much will be required for further manipulation—pressing, stamping and otherwise forming—and joining by welding, brazing, riveting, etc.

Plate. Rolled material ¼ in. thick or more is defined as plate. It is normally hot-rolled only; it therefore has a duller finish than most sheet and if high strength is required it must be heat treated.

The ability of aluminium plate to withstand rough usage has led to its use for dumper and tipper vehicles handling rock and ores; for railway mineral wagons; and for coal chutes. Its freedom from low-temperature embrittlement makes it the most suitable material for bulk storage of liquefied gases, such as methane, and there are many other applications in the chemical and general engineering industries.

The new 144-in. mill brings a big advance in available plate size: from 6 ft. to well over 10 ft. in width, and up to 50 ft. long. A feature of Noral plate is that it can be supplied with edges sawn straight to very close limits.

A rather specialized product is plate for aircraft construction. This is in high-strength alloys such as Noral B26S (D.T.D. 5040), and usually supplied in a thickness of several inches for machining into a structural component having stiffening members integral with the skin. This plate must have good mechanical properties in all directions, and must be free from residual stresses that would cause distortion during machining.

Welding in Russia

Following a two weeks' visit to welding research institutes in the Soviet Union a party from the British Welding Research Association returned with the impression that emphasis there is placed more on the application of new welding processes, and the associated problems, than on fundamental work for the sake of increasing knowledge. This arises from the all-out drive to expand production and the clear realization of the part played by welding toward that end. The importance of welding in the modern engineering and constructional programmes is probably more deeply appreciated in Russia than in this country

The BWRA *party comprised: the director of research, Dr. Richard Weck; the deputy director, Mr. H. F. Tremlett; the assistant director, Dr. A. A. Wells; and the chief metallurgist, Mr. P. T. Houldcroft. Five principal institutes were visited*

THE VISIT TOOK PLACE under the auspices of the U.S.S.R. State Scientific and Technical Committee, division for English Speaking Countries, and resulted from negotiations carried on with this Commission by Dr. D. A. Senior, the British Scientific Attaché in Moscow. It was arranged at this time to coincide with the opening of a Welding Exhibition in Moscow within the permanent Exhibition of the Economic Achievements of the National Economy in the U.S.S.R.

The party was impressed by the standard set by this exhibition and by some of the exhibits, particularly in the fields of cold pressure welding (dissimilar metals), friction welding and diffusion welding. Automation and mechanization of welding processes was the dominant theme. Specific items of interest were: a portable flash welder with contour transformer to deal with pipes up to 700 mm. in dia.; an automatic twin-head circumferential CO_2 welding machine for the same size of pipe, and a whole range of tungsten arc welders dealing with pipes in a variety of materials and sizes from 10 mm. dia. to 180 mm.

Mass-produced storage tanks

Methods to overcome the difficulties of distance and transportation to outlying areas were in evidence, and storage tanks up to 50 ft. dia. were shown which were prefabricated and rolled up for transport to site, where the rolls were subsequently pulled open by means of tractors and assembled with the minimum of site welding. Pipelines are dealt with in the same way, being welded in the flat and coiled for despatch. Using a tractor-pneumatic combination, workers expand the 600-m. coils into cylinders on site.

The acceptance standard for finish of welded components is lower than would be the case in this country; puckering on the face of sheet materials when welding on studs, for example, is accepted in the manufacture of car bodies. This, however, is considered of secondary importance to the functional quantities of what is produced.

Of the five research institutes visited, only one was entirely devoted to welding. One of the others was the research laboratory of a factory devoted to the manufacture of arc- and resistance-welding equipment; another was equivalent to a university department, and in two others welding was a department in an institute which had very much wider terms of reference. In only one of the institutes—the Baikov Institute in Moscow—is most of the research fundamental. In the other institutes, although some fundamental work is carried out, most of the research is directed towards the eventual development of new welding processes and new processes of manufacture.

Whilst the research and development effort in the Soviet Union in welding technology is on a very much bigger scale than it is in this country, this is to be expected from the difference in size between the two countries. There are some quite outstanding achievements, but there are also certain spheres where, owing to the special conditions in the Soviet Union, work is not as far advanced as in this country. Welding of aluminium alloys by the inert gas metal arc-welding process appears to be further advanced in this country than in the Soviet Union. On the other hand, the emphasis on submerged arc welding has led to the development of methods and suitable fluxes for the welding of aluminium alloys, titanium alloys and of copper. The joints appear to be of good quality and are claimed to have properties not very inferior to those of the parent material.

The conditions prevailing in many parts of the Soviet Union are unique, and processes may be developed under the pressure of economic factors different from those existing outside that country. Friction welding, for instance, can sometimes serve as an alternative to resistance flash welding and requires less power. The urge to develop this process came from the possibility of its use in areas of very limited power supply. Another illustration based on difficulties of supply is bare wire welding using steam as the shielding gas instead of argon or carbon dioxide.

It was apparent that the usual delay between the

development of a new process or method and the availability of equipment for industry is extremely short in the Soviet Union. This is probably due to the research workers having excellent facilities at their disposal for the manufacture of prototypes and production machines.

The party found the Soviet scientists with whom they came into contact very well informed on the literature of the West, but they greatly welcomed the opportunity of being able to ask questions on points which were not clear to them. They were very keen to receive considered critical comments on their papers, and expressed the desire to publish such criticism in their own journals.

Friction and diffusion welding

Very little has been done in this country to date with the friction-welding and diffusion-welding processes to which Russia is now paying much attention. The processes appear to offer a number of advantages, however, and the BWRA is to study their potential applications.

Friction welding. In this process, employing no external heat, the components to be welded are mounted in a device similar to a lathe, having a rotating headstock and stationary tailstock. The rotating and fixed components are brought into contact by pneumatic or hydraulic pressure when intense local heat is generated. At the moment of upsetting pressure reaches maximum and the drive is automatically stopped.

The process can obviously only be used where at least one of the components is a cylindrical or disc-shaped section, but it is claimed that the conversion of electrical energy into motive force is more economic than conversion into heat through a transformer, due to the inductance losses in the transformer secondary circuit; further, the process lends itself readily to mechanization.

Diffusion welding. The process consists, in essence, of bringing the clean surfaces of the components together in a vacuum, when the application of heat and pressure results in the atoms diffusing at the faying surfaces to produce an alloy. Joints in dissimilar materials, *e.g.* metal to non-metal, can be produced in this way.

RUSSIAN WELDING SPECIALISTS VISIT BRITAIN

Following the visit of British welding specialists to the Soviet Union, a Russian welding mission made an exchange visit to this country during September/October. The members of the mission were: Mr. B. E. Paton, academician of the Ukrainian Academy of Sciences, Director of the Soviet Institute of Welding; Mr. V. P. Sokolov, Chief Engineer, Soviet Welding Plant; Mr. V. P. Andreev, Chief of the Department of Welding of the Soviet Research Institute; Mr. M. I. Baranov, engineer in welding applications in the automobile industry; and Dr. I. K. Pokhodnya, Chief of Laboratories, Soviet Institute of Welding. Mr. L. B. Kolesnikov accompanied the party as interpreter.

A tour of the BWRA laboratories was made on October 4, the visitors later being the guests of honour at a dinner given by the senior research staff of the Association. In the discussion of comparative approaches to welding research which followed, Mr. Paton said that his party had been impressed by what they had seen, particularly in relation to the study of the strength of welded components. He also referred to the growing use being made of CO_2 welding which had, apparently, reached a more advanced stage in Russia than is common in this country. The process is now in regular use there in the construction of pressure vessels.

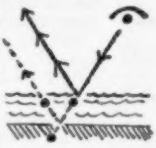
Visitors and their hosts at Abington seen in the photograph are, left to right: Dr. A. A. Wells (BWRA), Mr. V. P. Andreev, Major J. H. Dixon (interpreter), Mr. M. I. Baranov, Mr. V. P. Sokolov, Mr. R. M. Pendrous (BEMA), Mr. A. O'Neill (BWRA), Mr. P. T. Houldcroft (BWRA), Mr. B. E. Paton, Mr. R. G. Burt (BWRA), Mr. L. B. Kolesnikov, Dr. R. Weck (BWRA), and Dr. I. K. Pokhodnya.

Electrical Aids in Industry *Data Sheet* **No. 13**

Infra-Red Heating

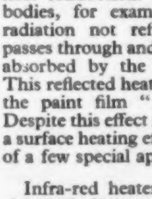
Infra-red heating is the name given to the method of using in industrial processes radiant heat from heaters specifically designed for that purpose. This differentiates it from methods employing both radiation and convection, as in furnaces, although the effect of the radiation is much the same in both cases.

Radiant heat provides a higher rate of heat transfer to bodies not highly reflective than does convection, unless high-velocity forced convection is used. The rate of heating of a body depends on the intensity of radiation on its surface, the proportion absorbed by the surface and, after that, on heat conduction. In heating very thin bodies, for example paint films, the radiation not reflected nor absorbed passes through and is in turn reflected or absorbed by the underlying material. This reflected heat is partly absorbed by the paint film "on the way back". Despite this effect infra-red gives mainly a surface heating effect except in the case of a few special applications.



Infra-red heaters mainly use metal-sheathed elements in special reflectors, but infra-red lamps with internal reflectors are still used in special cases. Other types use silica-sheathed elements or quartz-sheathed lamps in reflectors. A wide range of heaters is available with simple mounting arrangements to enable heat to be applied quickly and effectively either in a production line or in some odd corner.

Control of the charge temperature is effected by regulating the heating time and power. In the case of a moving charge, this is done by adjusting the conveyor speed and the number of heaters in circuit, i.e. by adjusting the effective length of the oven. Some of the heaters may be controlled by energy regulators or adjustable transformers.



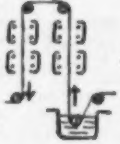
The advantages of infra-red heating over convection heating include reduced heating times, reduced floor space, lower installation costs, almost instant starting, ability to focus the heat, and flexibility in effective oven length. Infra-red ovens can often be mounted in the roof, saving valuable floor space. Infra-red heating is not generally favourable for heating large bodies of low heat conductivity.

Paint Stoving

Many paints, particularly synthetic enamels, and including synthetic wood finishes, are well suited to infra-red heating, and many products ranging from small components to complete motor cars are being successfully stoved. Infra-red heating reduces stoving times very considerably and often improves the finish.

Moisture Extraction

Infra-red can provide high drying rates, either of liquid surface films or of thin absorbent materials. Sheathed element heaters usually give the highest rates, but lamps are sometimes used where the dried material is particularly heat-sensitive. Applications include such tasks as drying of paper and textile products, bottle seals and labels, clayware glazes and many others.



Plastics

Infra-red is widely used in the plastics and allied industries for such typical applications as softening and curing of plastic sheets and belts, heat setting of nylon and similar fabrics, drying and curing of plastic and rubber coatings and others where a plastic forms the whole or part of a product.

The above are just a few examples of successful applications of infra-red. In many other processes infra-red heaters can often be fitted quickly and cheaply, to save time, labour and floor space and, therefore, money.

PEOPLE

AT THE ANNUAL MEETING of the British Standards Institution **Mr. R. E. Huffam** (former U.K. co-ordinating director of Unilever Ltd.) was re-elected for a third term of office as president of B.S.I.

Sir Herbert, Sir Roger Duncalfe (former chairman and managing director of British Glues & Chemicals Ltd. and a former president of B.S.I.) and **Mr. John Ryan** (vice-chairman of the Metal Box Co. Ltd.) were re-elected deputy presidents of B.S.I.

Mr. Walter Somers, managing director of Walter Somers Ltd., Hales Owen, has left for a six weeks' business tour of Australia.

Mr. S. H. Brooks has been appointed works manager (iron) at Appleby-Frodingham Steel Co., a branch of the United Steel Cos. Ltd. He succeeds Mr. N. D. Macdonald, who becomes general works manager at Workington Iron & Steel Co.

Mr. A. E. Richards has been appointed managing director of Universal Matthey Products Ltd., the joint subsidiary company of Universal Oil Products Co. and Johnson, Matthey & Co. Ltd.

Mr. C. H. T. Williams, J.P., was installed last month as the Master of the Company of Cutlers in Hallamshire. Mr. Williams is a director of Tube Investments Ltd. and is deputy chairman of the Executive Board of the Iron and Steel Division of T.I., which comprises the Park Gate Iron & Steel Co. Ltd., Renishaw Iron Co. Ltd. and Round Oak Steel Works Ltd., of which companies Mr. Williams is chairman.

Mr. Williams' career has been closely associated with the Park Gate Iron & Steel Co. which he joined in 1912. His appointments with that company have included the position of rolling mills superintendent, works manager and managing director.

His Royal Highness Prince Harald, the 23-year-old Crown Prince of Norway, is to open a new £2½ million sinter plant at Workington Iron & Steel Co. on December 6.

OBITUARY

Lord Verulam, a leading figure in the world of metals and metallurgy and a well-known industrialist, died last month at the age of 50. Chairman of Enfield Rolling Mills Ltd. since 1949, he was also chairman of the Engineering and Lighting Equipment Co. Ltd., and Sternol Ltd., and a director and member of the London Committee of the District Bank Ltd. He was also a member of the council of the Industrial Welfare Society.

Although he had read zoology at Christ Church, Oxford, Lord Verulam decided very early in his career to apply himself to engineering and metallurgical production. He was appointed managing director of Enfield Zinc Products Ltd. in 1933, a director of Enfield Cables Ltd. in 1936, and its managing director from 1943 onwards. He was a consistent supporter of the Industrial Co-partnership Association, but it will be for his outstanding work with the Subsistence Production Society of the Eastern Valleys of Monmouthshire for the five years before the last war that he will long be remembered.

He was a Fellow of the Royal Geographical Society, a Companion of the Institution of Electrical Engineers, and a Fellow of the Institute of Industrial Administration. He is succeeded by his brother, Mr. John Grimston, managing director of Enfield Rolling Mills.

The death occurred suddenly last month of **Mr. F. E. C. Probyn** at the age of 57. Since 1958 he was chief mechanical engineer at the Ebbw Vale Works of Richard Thomas & Baldwins Ltd.

Mr. Probyn joined Baldwins Ltd. at Panteg, in 1920 and, after five years' apprenticeship in the workshops and seven years in the drawing office, he was appointed assistant steelworks engineer. In 1936 he moved to Richard Thomas & Co. Ltd., as engineer on the Wellfield Works, Swansea, and transferred to the South Wales Group in 1937 as assistant engineer, tinplate section. The following year he moved to Ebbw Vale and was placed in charge of hot and cold mills maintenance. Prior to his last appointment he had been deputy chief mechanical engineer since 1952.

Mr. Probyn had served on the engineering committee of the Iron and Steel Institute's iron and steel engineers' group and on the new engineering techniques committee of the British Iron and Steel Research Association's plant engineering division. In the course of his duties he had made several visits to the Continent and America. He was a past president of the Ebbw Vale Metallurgical Society.

The death has taken place of **Mr. D. Luther Phillips,** well known to many members of the British Iron and Steel Research Association and people in the steel industry, particularly in South Wales. He joined BISRA in its early days—in 1946—and for eight years led the Sketty Hall team in a succession of important research projects related to the coating of steel. He retired from the headship of the Sketty Hall laboratories in 1954, but continued to act in a consultative capacity.

Mr. Phillips, after graduating with honours in chemistry from the University College of Wales in 1911, was awarded an industrial busary at the iron and steel works of Baldwins Ltd., at Landore. Subsequently he held the posts of chief chemist and metallurgist, blast-furnace manager, and works manager. In 1931 he took up the position of senior research officer of the local Steel Plate Association in the metallurgical department of the University College, Swansea, and in 1937 visited the U.S. on behalf of the local research committee.

It was at that time that his work on strain age hardening culminated in a joint paper with Dr. C. A. Edwards and Mr. H. N. Jones, a work that aroused considerable interest as indicating a new approach to an important problem.

Readers who know **Mr. T. G. (Tom) Munro,** of Southern Forge Ltd., will be deeply grieved to know of his death on October 25 after a short illness. Mr. Munro, who joined the company at its inception, was appointed sales manager in 1959, and he will be sadly missed both by his colleagues and his many friends in industry.

INSTRUMENTATION

New lightweight X-ray unit

A portable X-ray unit of 150 kV. capacity and a weight of 51½ lb. has been introduced by Pantak Ltd., of Vale Road, Windsor, Berks. The new unit, known as the Baltospot G150, is available in two models, the type D head having a 60-deg. field whilst the type P has a 360-deg. field. In both units the beam angle is 35 deg. and the head is offset. The focal spot size of the tungsten target is 1·5 mm. × 1·5 mm. in the E150D whilst that for the G150P is 0·8 mm. × 2·1 mm. A particular feature of the offset head is its use, especially in the panoramic version, in the examination of closed vessels of small diameter, the examination of a 3-ft.-dia. tubular vessel with a welded dished end being well within the capacity of the unit.

Sulphur hexafluoride is used for both insulation and cooling of the X-ray tube, forced circulation cooling of the anode being effected by means of an internal blower. The tankhead is of drawn aluminium with bolted dished ends and amongst the numerous protection devices fitted are shock-absorbent mountings for the tube in the tankhead and further shock-absorbent mountings for the tankhead in the cradle. A thermoswitch is fitted to guard against excessive temperature rises.

The control unit operates from a 220-V. 50/60-cycle a.c. supply, using 6 amps., and accommodates mains fluctuations of 10% either way. Experimental exposure charts for 16-in. and 28-in. focus/object distances are supplied in the lid.

The 'Elliscope' pocket microscope

Industrial pocket microscope

Ellis Optical Co. have designed and produced a high-powered pocket microscope which has optically worked lenses and has a magnifying power of from 20 times up to 40 times.

An advantage is the mirror at the base which when turned towards a light source reflects light on to the object to be examined. Magnification can be increased by extending the sliding tube and correct focusing is easily obtained by adjusting the knurled ring. The circle of field is approximately ⅛ in.

Particulars may be obtained from the manufacturers: Ellis Optical Co., Mayday Road, Thornton Heath, Surrey (Thornton Heath 3601).

Vapour-phase-process chromatograph

The Quality Control Division of Elliott Brothers (London) Ltd., a member of the Elliott-Automation Group, is now marketing the new C.E.C. vapour-phase-process chromatograph.

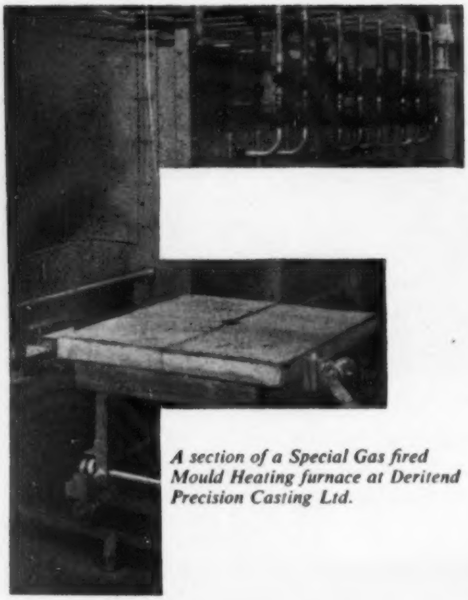
The chromatograph, type 26-212, is designed for a very wide range of applications and is particularly suited for automatic closed-loop control.

Special features of the type 26-212 chromatograph include: (1) High speed and accuracy—a complete analysis of all hydrocarbons up to and including Petenes is achieved in 29 sec. with an accuracy of 1% of full scale.

(2) Multiple-stream analysis—up to eight streams can be automatically analysed in repetitive sequence. An over-ride switch is available for analysis of any selected stream repetitively.

(3) Multiple columns—if a number of streams require analysis and these cannot all be performed with one column, it is possible to fit any additional columns which are automatically switched in when the streams which they must analyse are being passed to the chromatograph.

(4) Use with the Taylor control system—a feature jointly developed with the Taylor Instrument Co., a chromatograph can now be used in a closed-loop control system. A successful installation has been carried out on a de-ethanizer tower in a Texas natural-gas plant.



A section of a Special Gas fired Mould Heating furnace at Deritend Precision Casting Ltd.

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